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THE INSTITUTION OF

PRODUCTION ENGINEERS JOURNAL

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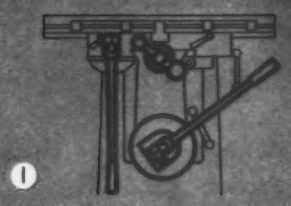

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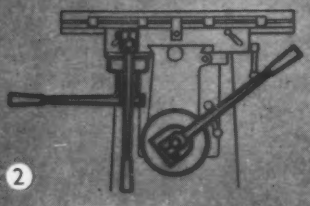

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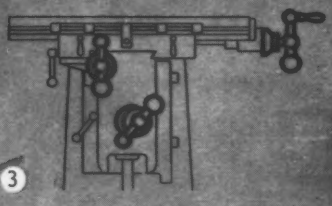

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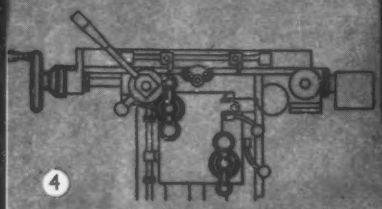
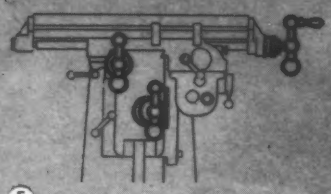
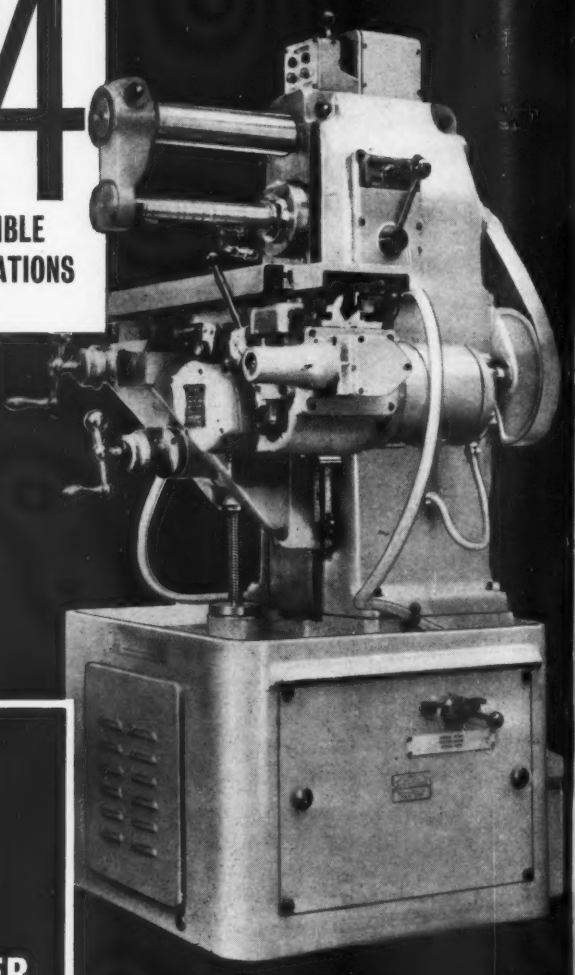


4 Multiform—semi-automatic cycle.



5 Normal automatic feed.



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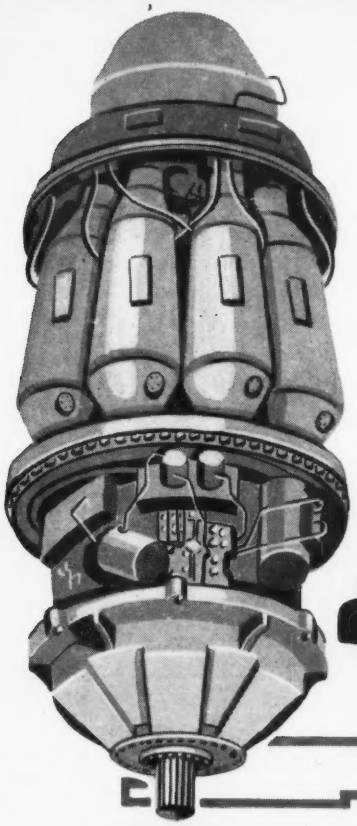

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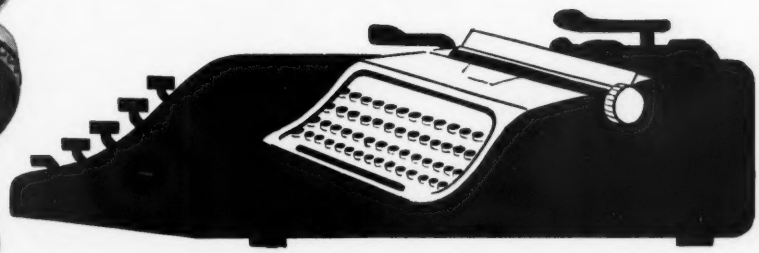

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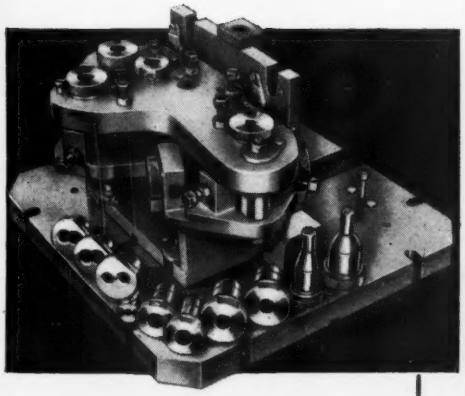

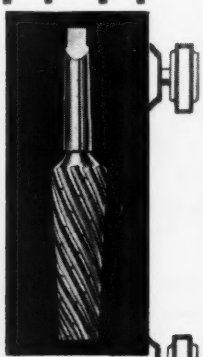

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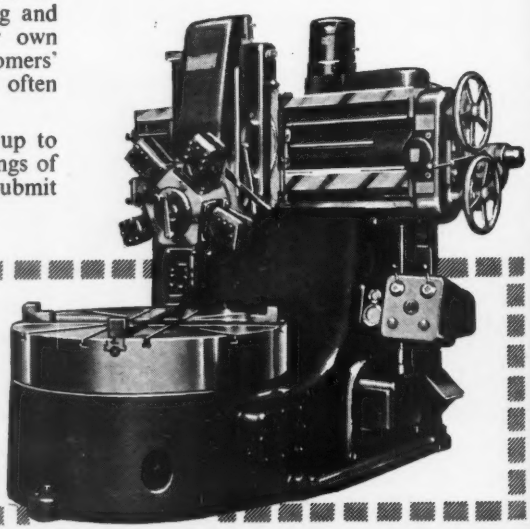

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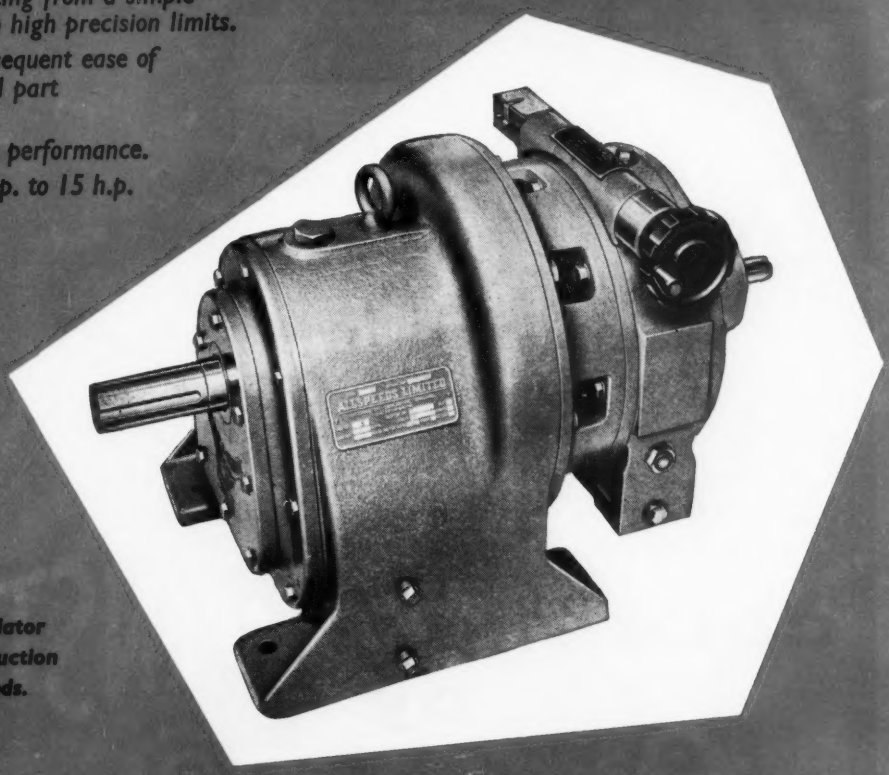

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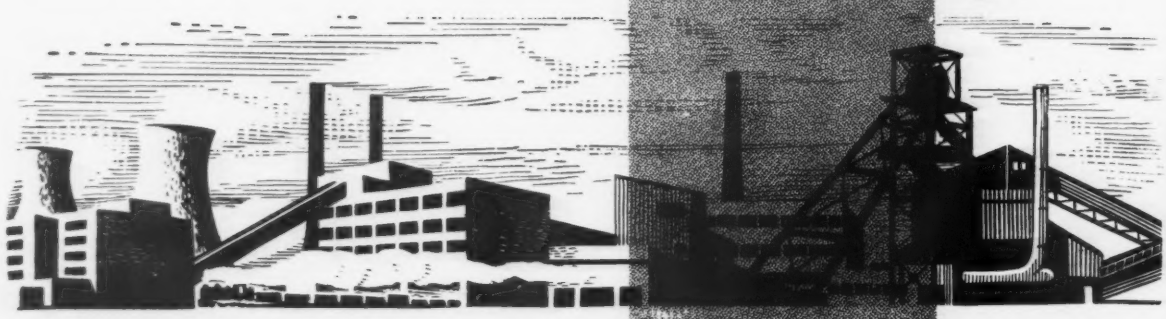

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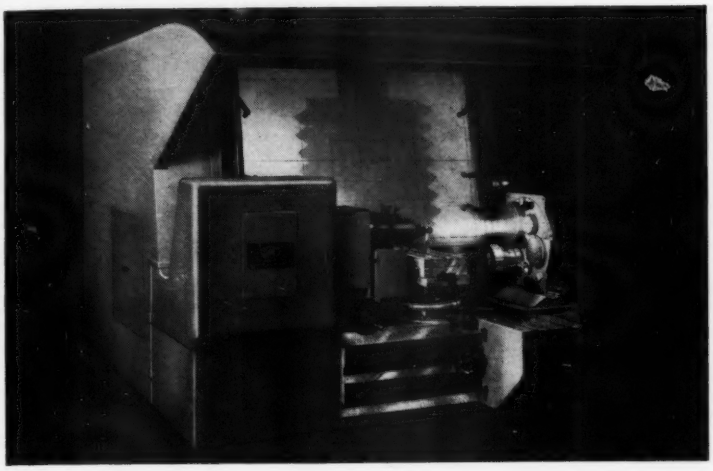

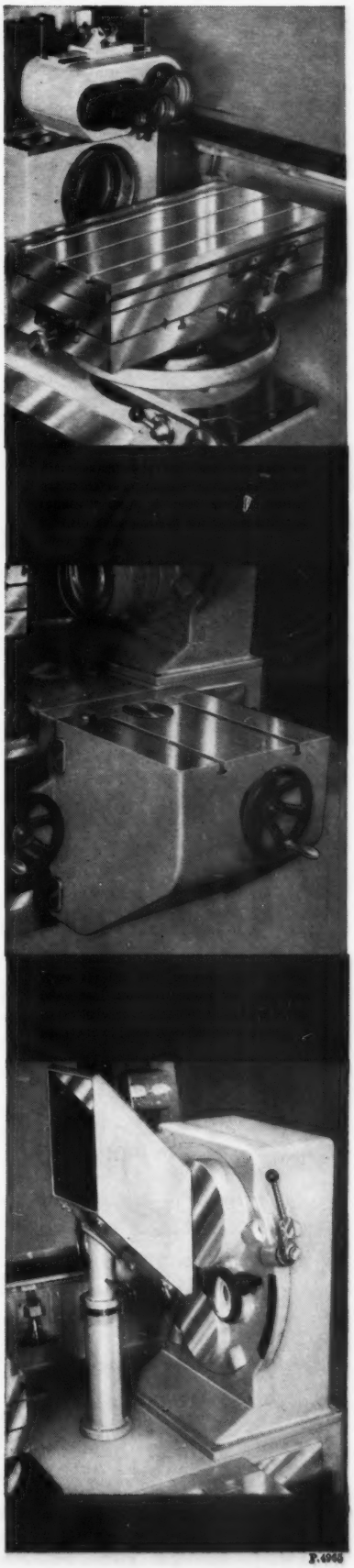

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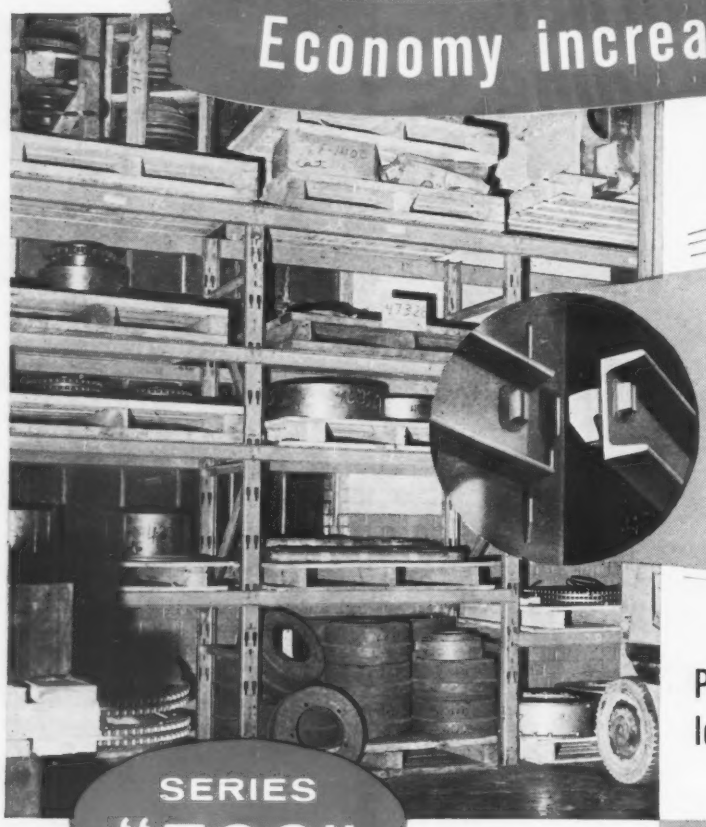

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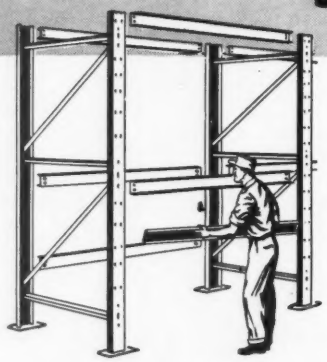

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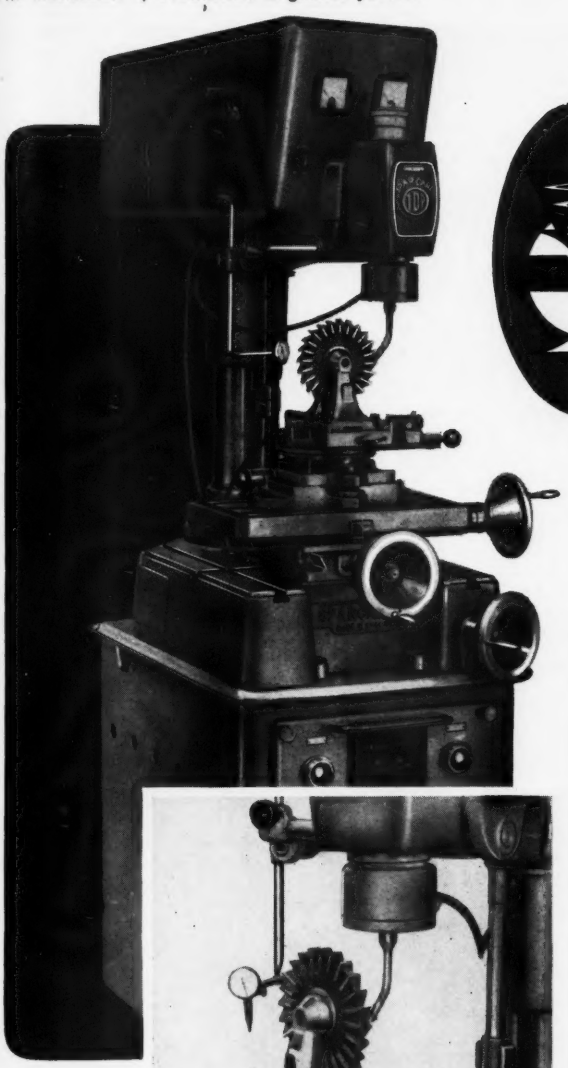

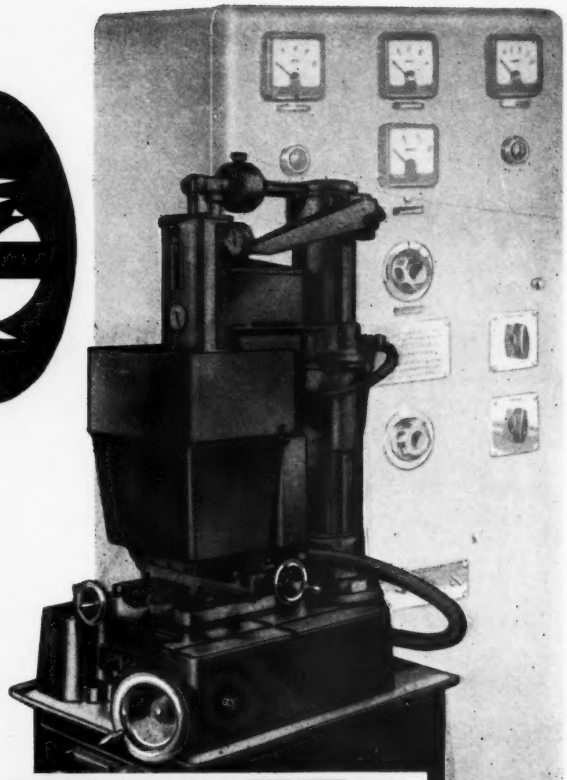

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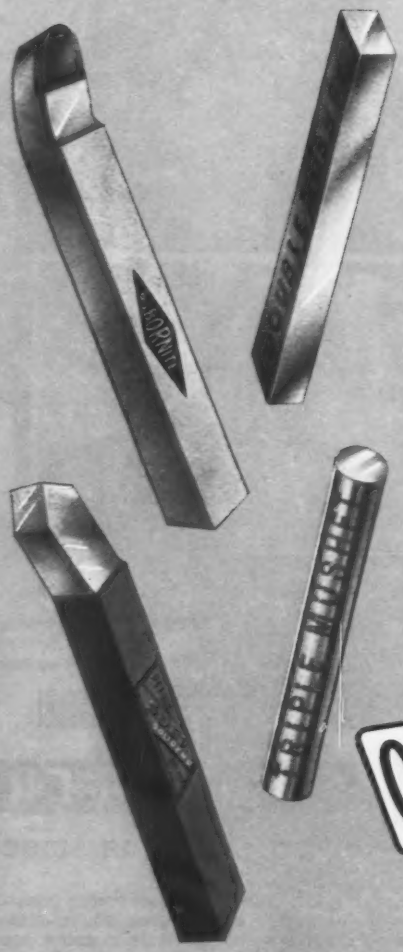

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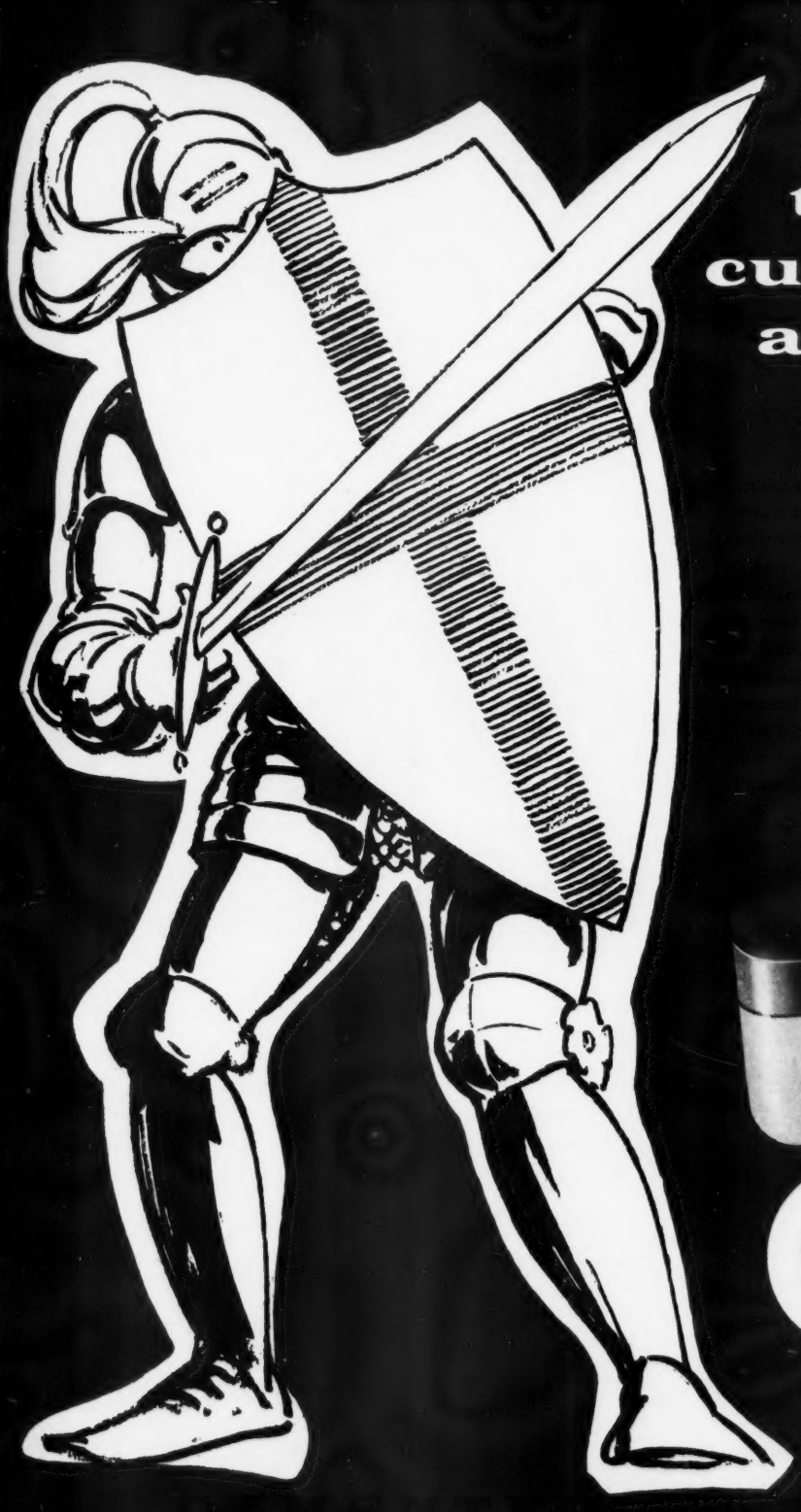

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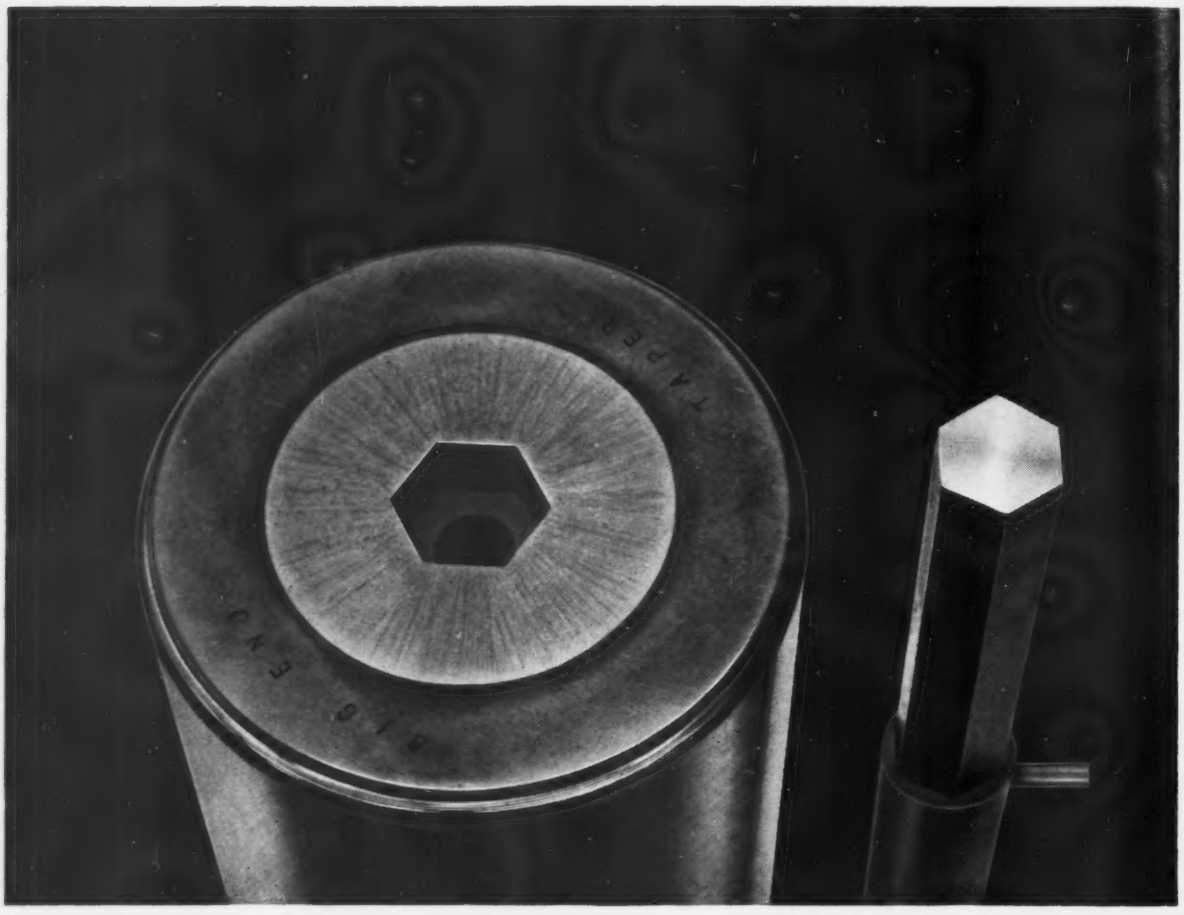

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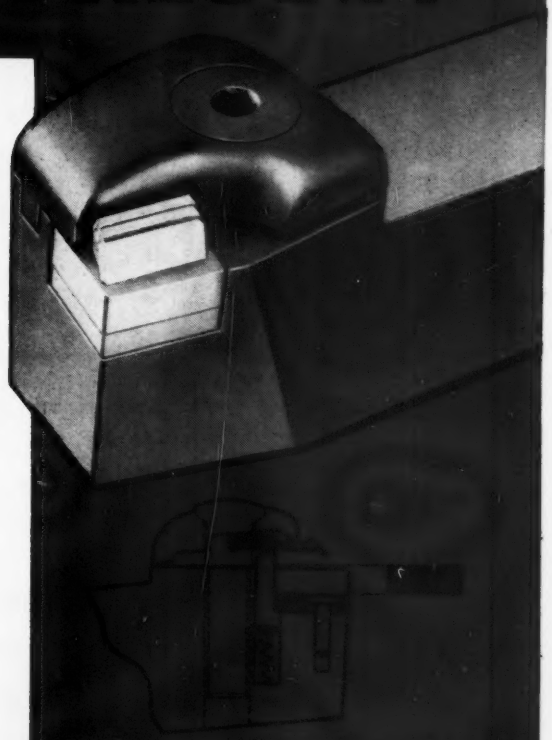

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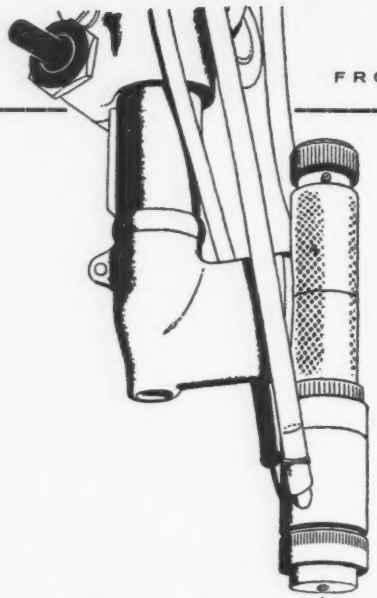

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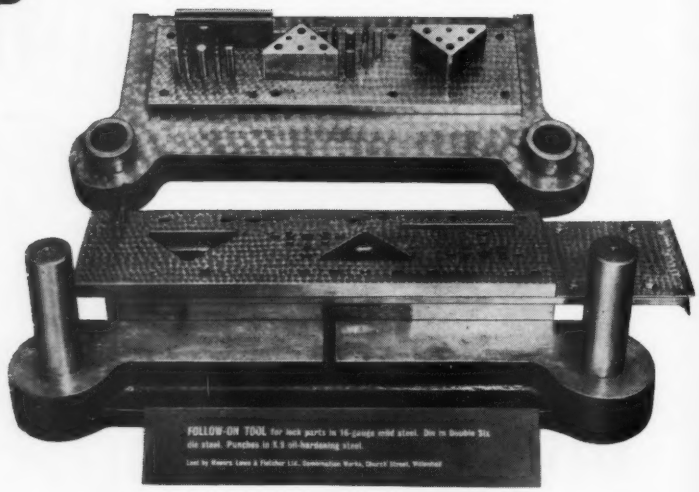
Camborne, Cornwall. Telephone: Camborne 2275 (10 lines)
44 Brook Street, London W.1. Telephone: Hyde Park 9444

One of the companies of the world-wide Holman Group, which has agents, branches and technical representatives throughout the U.K. and in 84 other countries.

An ALL-ROUND steel for ALL-ROUND service

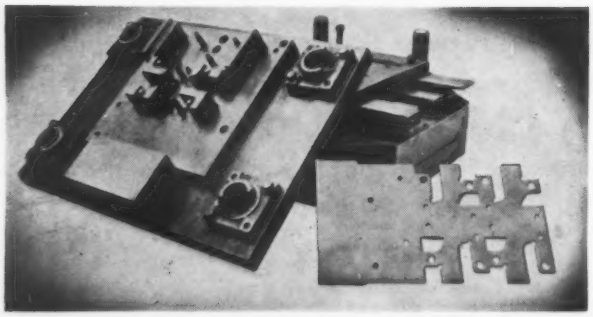


FOLLOW-ON TOOL for lock parts in 16-gauge mild steel. Die in Double Six die steel. Punches in K9 oil-hardening steel.

Photograph by courtesy of Messrs. Low & Fletcher Ltd., Combination Works, Church Street, Willenhall.

Edgar Allen K9 Die Steel was perfected in answer to a demand for a non-shrinking steel easy to heat-treat, yet giving good long production runs.

For most jobs where price or the less exacting nature of the work do not suggest the use of the more expensive die steels, you will be surprised how well K9 Steel will fill the bill. Write for full particulars of our complete range of Die Steels.



Blanking Tool of K9 Steel with product.

K9 STEEL *for* DIES

Edgar Allen & Co. Limited
IMPERIAL STEEL WORKS · SHEFFIELD · 9

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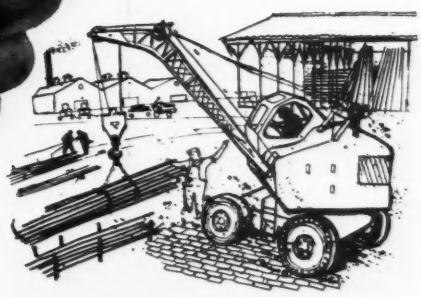

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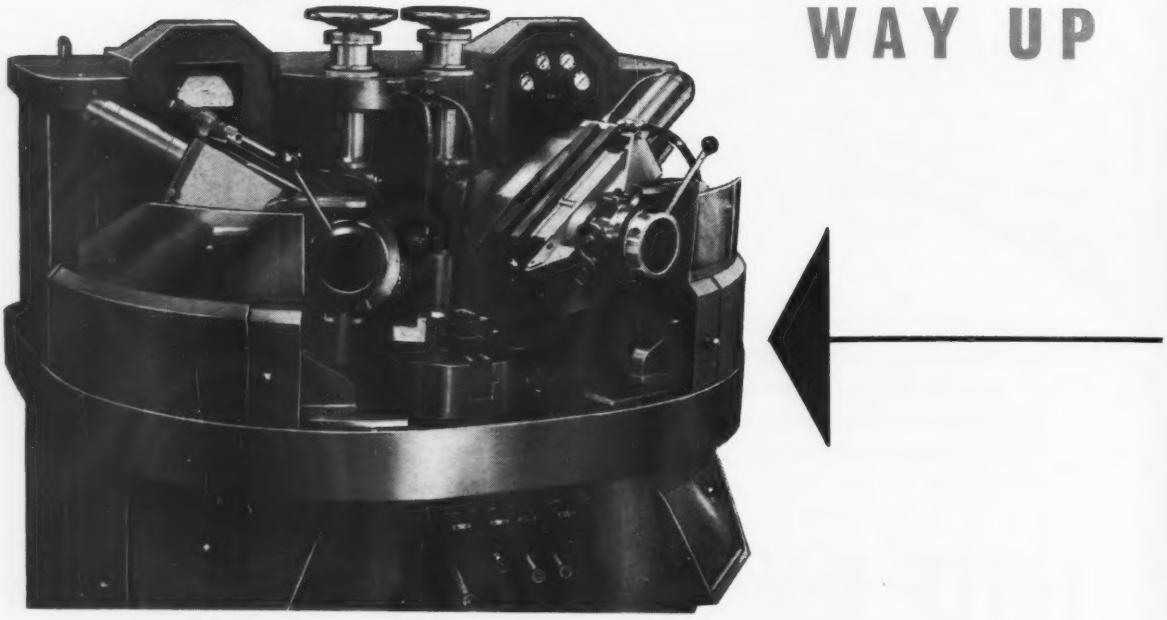
THE RIGHT WAY UP



For many production jobs it is a distinct advantage to have your work piece vertically mounted on a vertical spindle lathe. This machine is simple to set up and load and extremely rigid.

The VERTIMAX Vertical Spindle Production Lathe represents the best in this type of machine. Its features include an air-operated chuck and spindle brake, two independent and adjustable tool slides, which can be swung through any angle, infinitely variable hydraulic feed, automatic operation, grouped controls, and it takes the *minimum of floor space.*

For a brochure giving full details of the VERTIMAX production lath , write to:

CHARLES CHURCHILL AND COMPANY LIMITED

COVENTRY ROAD, SOUTH YARDLEY, BIRMINGHAM 25. BRANCHES: LONDON, GLASGOW, NEWCASTLE, MANCHESTER

TAS/CC14

High power/weight ratio
Fast work
Low running cost—
that's HOLMAN pneumatic tools

The Holman Rotogrind — like all Holman tools — does a first-class job economically. It's fast — 8000 r.p.m. at 80 lbs. per sq. inch. It's light — only 7½ lbs. without the wheel, and remarkably easy to handle for such a powerful tool. And it costs very little to run. It's a Holman tool — so it's built to last, and take heavy work in its stride. A simple, friction-free, cartridge-type motor . . . hard chrome plate on all parts that have to take heavy wear . . . the exclusive Holman blade-pressure control system — all these add up to long working life and the minimum running cost. And remember that *running cost* is the *real* cost of pneumatic equipment.
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PNEUMATIC EQUIPMENT

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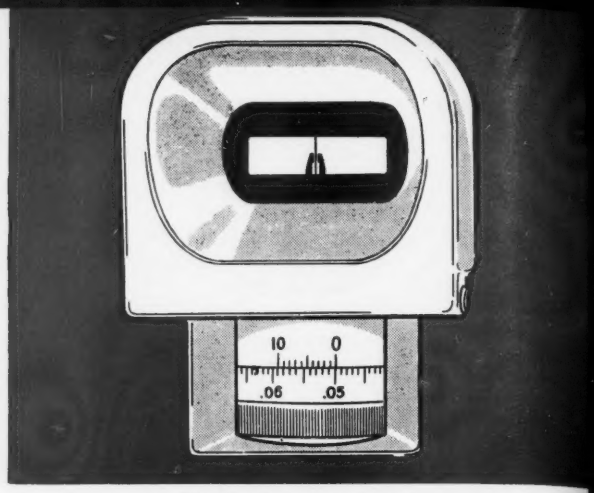
HK13

ACCURACY at a glance

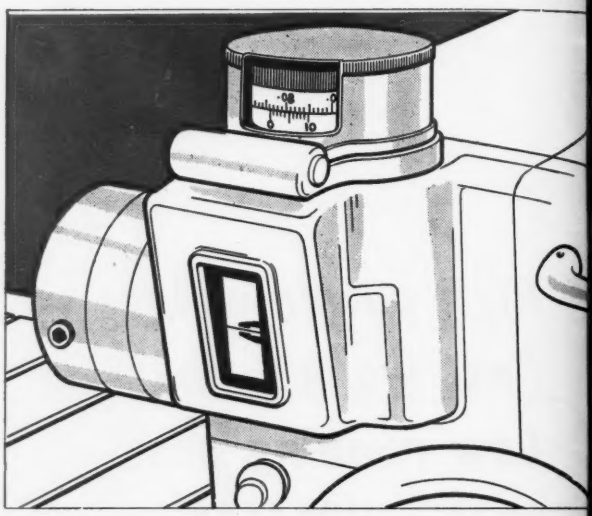
With projection screens arranged on the bed, horizontal head and cross-rail, this extremely accurate jig boring and milling machine is capable of high output in large-capacity precision work. The projection screens show magnified images of the standard scale graduation lines, enabling a high degree of setting accuracy to be obtained together with exceptional ease of operation.

The spindle running true to within *.00005 inch (0.001 mm.)* of very robust design revolves in rigid reinforced tapered roller bearings of GSIP manufacture.

For permanent working accuracy, the elevating screws of the cross-rail are hydraulically relieved before being electrically driven, so that the upper flanks of the threads on which the cross-rail rests are not subjected to wear.

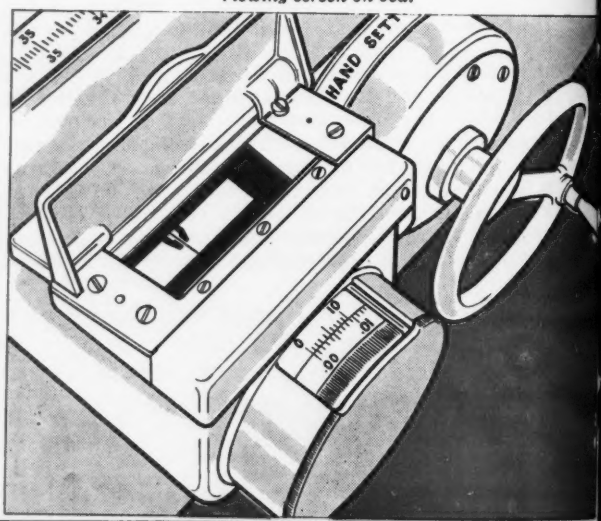


Viewing screen on cross-rail.



Viewing screen on horizontal head.

Viewing screen on bed.



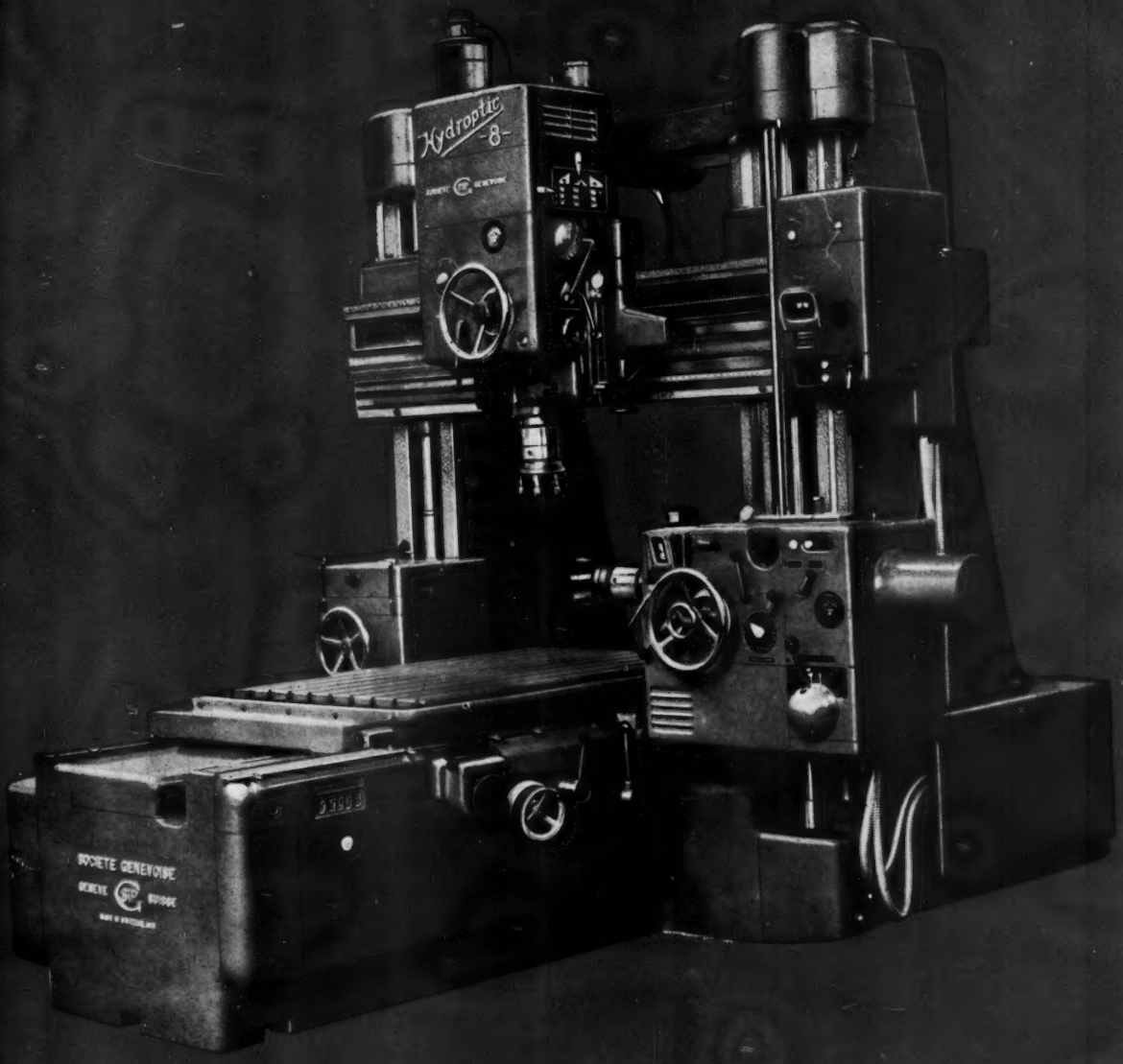
The installation and service of this machine is carried out by the Area Engineers of Sogenique (Service) Ltd., under the GSIP guarantee. Please write for literature or further information.

SOCIETE GENEVOISE LTD

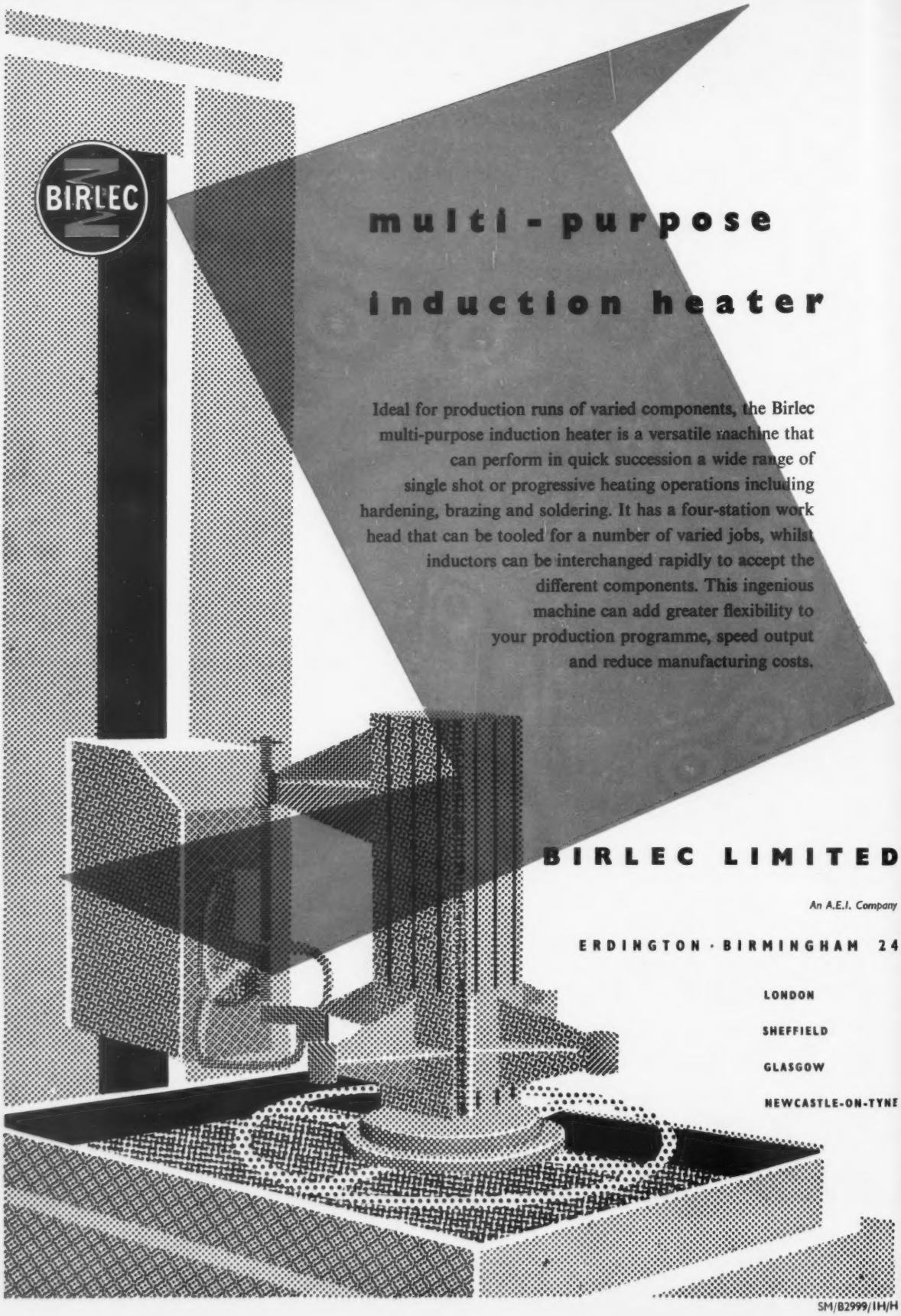
NEWPORT PAGNALL · BUCKS · TELEPHONE 460-1-2

guaranteed setting accuracy ·0002 in.

Nominal travel of table	55 in.-1400 mm.
Nominal spindle head travel	40 in.-1000 mm.
Maximum distance from table top to spindle nose	39½ in.-1000 mm.
18 spindle speeds 40-52-65-80-105-130-165-210-265-330-420-530-625-800-1000-1250-1600-2000	
Drilling capacity (in cast iron)	2¾ in.- 60 mm.
Boring capacity	10 in.-250 mm.
GUARANTEED ACCURACY FOR ALL SETTINGS OF WORK-TABLE AND SPINDLE HEAD SADDLES	0.0002 in.-0.005 mm.



HYDROPTIC 8P



multi-purpose induction heater

Ideal for production runs of varied components, the Birlec multi-purpose induction heater is a versatile machine that can perform in quick succession a wide range of single shot or progressive heating operations including hardening, brazing and soldering. It has a four-station work head that can be tooled for a number of varied jobs, whilst inductors can be interchanged rapidly to accept the different components. This ingenious machine can add greater flexibility to your production programme, speed output and reduce manufacturing costs.

BIRLEC LIMITED

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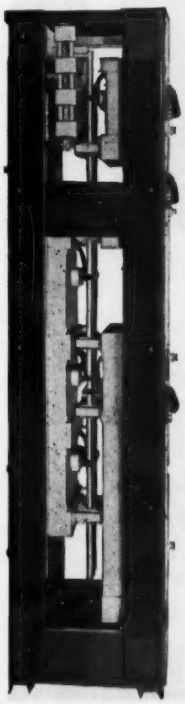
Design Leadership in action

CONTROL CENTRES

The newest concept for modern industry

Square D introduces a completely new concept of multi-motor control—Class 8998 Control Centres. They are specifically designed to meet the growing trend in modern industry towards centralization of motor control equipment. Square D Control Centres are built up from interchangeable units, vertical sections and bus bar structures of standardized design. This new concept gives all the benefits of standardization *plus* the flexibility to meet detailed customer requirements.

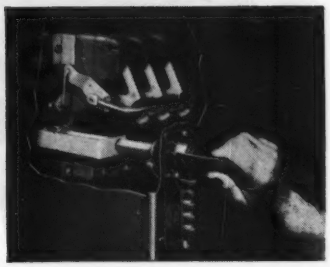


Greater safety
Buses are fully enclosed, rigidly supported and have ample cross section. Round vertical bus bars withstand mechanical stresses in all directions. Circuits isolated by individually enclosed plug-in units and horsepower rated load-break disconnect switches.

Increased flexibility
Individual units or complete sections can easily be added, removed, or exchanged. Designs are standardized.

Installation economy
Only one set of feeder cables required. Factory installed bus distributes power to branch circuits. Load side wires easily laid in handy wiring troughs.

Neat appearance
No unsightly grouping of separate pieces.



Simplified maintenance
Centrally located control units provide greater accessibility for systematic inspection and maintenance.

Compact installation
Each vertical 90 inch high section accommodates up to 6 combination starter units. Back-to-Back Construction requires no more space.

Write for Control Centre Bulletin 8998

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SD 26

It's well worth looking into because it's a Plannair blower, and power for size, is the most effective you can find anywhere. In the aircraft and electronic fields, for cooling or heating, Plannair blowers have proved outstanding in numerous applications and are now being specified by design engineers in the electrical and engineering industries.

This latest example of superior Plannair design is a two stage 6″ blower (details of which are given below) providing manufacturers with a dynamic, effective answer to problems involving air movement.

When you contact Plannair your problem days are numbered. The Company's specialised facilities and helpful advice are freely available. All you have to do is —'phone Leatherhead 4091.

PLANNAIR BLOWER 6PL122-79
(Axial Flow—2 stage)
Blade tip diameter of impeller 6″
Volumetric airflow 310 c.f.m. at a maximum pressure rise of 1.3″ s.w.g.
230v. single phase 50c capacitor type 2,900 r.p.m.

PLANNAIR

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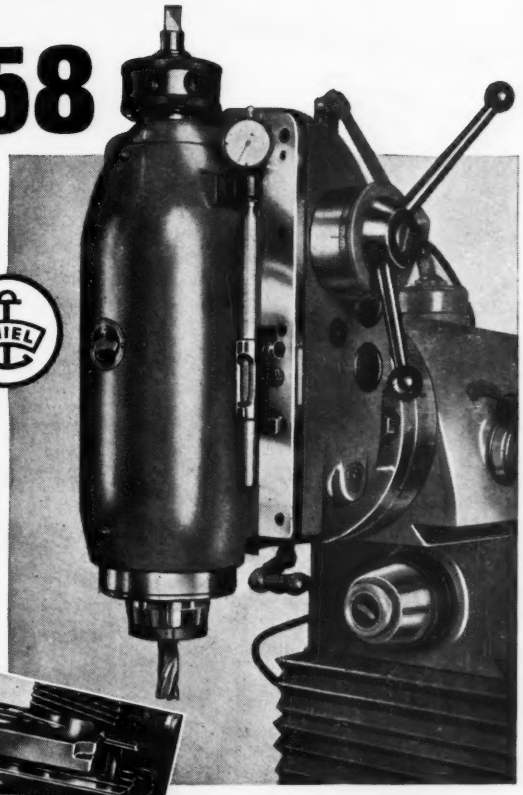
PLA 17

3 New Attachments

make the THIEL 158

your Toolroom's most VERSATILE Machine

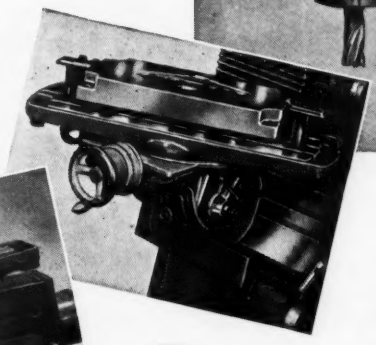


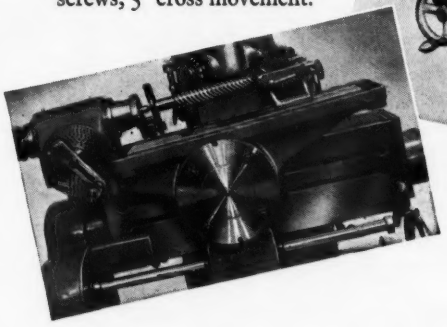
1 New Jig Boring Head

Precision head, running in extra wide ways, equipped with three power feeds, 7″ power operated slide movement complete with dial gauge and slip gauge holder, 12 spindle speeds available through machine, 360° swivel.

2 New Table

Universal swivelling and tilting compound table with large clamping area. Heavy rigid construction and fitted with hardened and ground lead screws, 5″ cross movement.





All these new attachments can be fitted to any one of the hundreds of Thiel 158 Machines already in the field.

3 New Spiral Milling Attachment

Ideal for manufacturing cylindrical or conical reamers, milling cutters as well as worms and a host of other parts.

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MACHINE TOOL CO. LTD.

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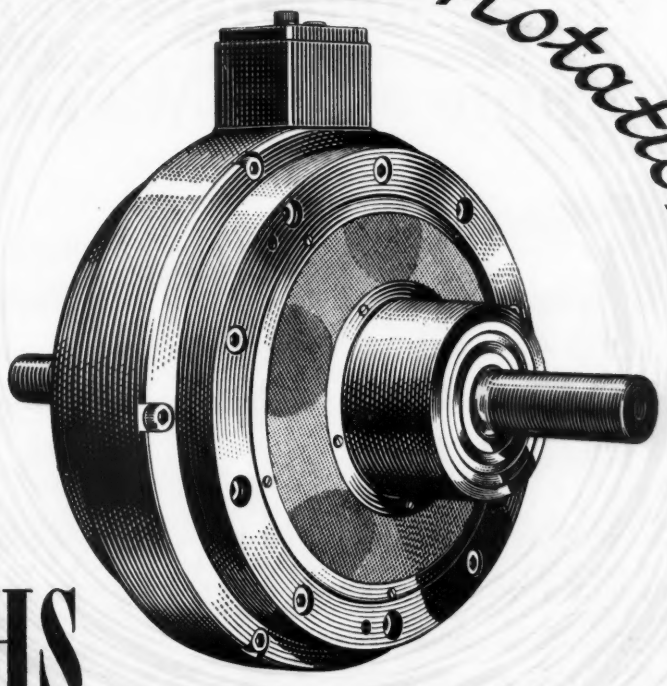
THIEL VI

Made by James Neill & Co. (Sheffield) Ltd. and obtainable from all distributors UX11

Revolution in Rotation



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which combines:—**the resilience of the hydraulic coupling and the positiveness of the frictional coupling.** It is revolutionary in that driving and driven elements are coupled by magnetically-activated particles. It has these advantages:—

Accurate torque control
No mechanical engagement and thus negligible wear
Accurate torque limiting slip on overload
Acts as brake or coupling in **either** direction

Perfectly smooth operation
No slip rings—excitation coil is stationary
Remote control at any distance
Dynamic and static coefficients of friction equal

The range comprises eight standard units with torque capacities from ½ to 200 lb/ft.

SMITHS Magnetic Particle COUPLING is unique, its potentialities enormous. Let us advise you, therefore, how best to use it in your particular field.

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You've never seen masonry drilling to match the performance of Durium Drills. They cut sharp, accurate holes with a speed of penetration and silent efficiency that will amaze you. And, with their almost diamond-hard Durium tip, and their special patented flute to eject spoil and prevent clogging, they stand up to the abrasive action of masonry long after ordinary drills have given up!

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RESHARPENING SERVICE for even longer life!

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Whether used by hand or power, Durium Drills save their cost over and over again in **extra** efficiency, **extra** long life.

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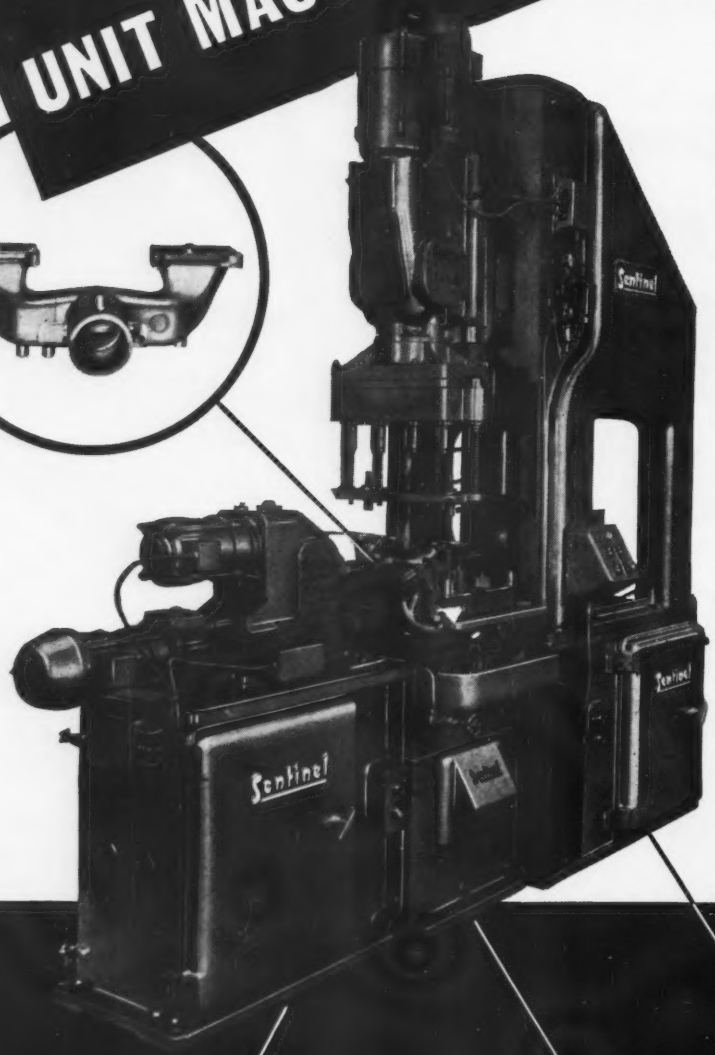
Sentinel UNIT MACHINES

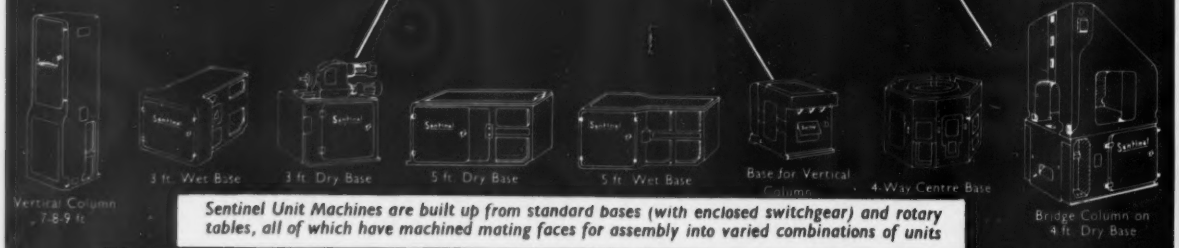
FAST VERSATILE ECONOMICAL



SENTINEL UNIT MACHINES incorporating the Renault-France system electro-mechanical heads.
Built for—Drilling, Boring, Facing and Chamfering. 8 different types of Manifolds (see *inset*). Two manifolds are loaded, pneumatically located and clamped.
Press a button to start—and in less than 30 seconds the machining cycle is completed!

AN EXAMPLE OF FLEXIBILITY

This Unit Machine comprises a
3 ft. Dry Base, and an EMH 10 with Boring, Facing and Chamfering Tools.
3 way Centre Base.
4 ft. Dry Base, and an EMH 10 with Boring, Facing and Chamfering Tools.
Bridge Column, and an EMH 20 with a 12 multi-spindle head.


Vertical Column 7-8-9 ft
3 ft. Wet Base
3 ft. Dry Base
5 ft. Dry Base
5 ft. Wet Base
Base for Vertical Column
4-Way Centre Base
Bridge Column on 4 ft. Dry Base

Sentinel Unit Machines are built up from standard bases (with enclosed switchgear) and rotary tables, all of which have machined mating faces for assembly into varied combinations of units

SENTINEL (SHREWSBURY) LTD SHREWSBURY ENGLAND

Telephone: SHREWSBURY 2011 Telegrams: "SENTNOLL SHREWSBURY" London Office: 15 CONDUIT STREET LONDON W.1 Telephone: MAYFAIR 2675

P4108

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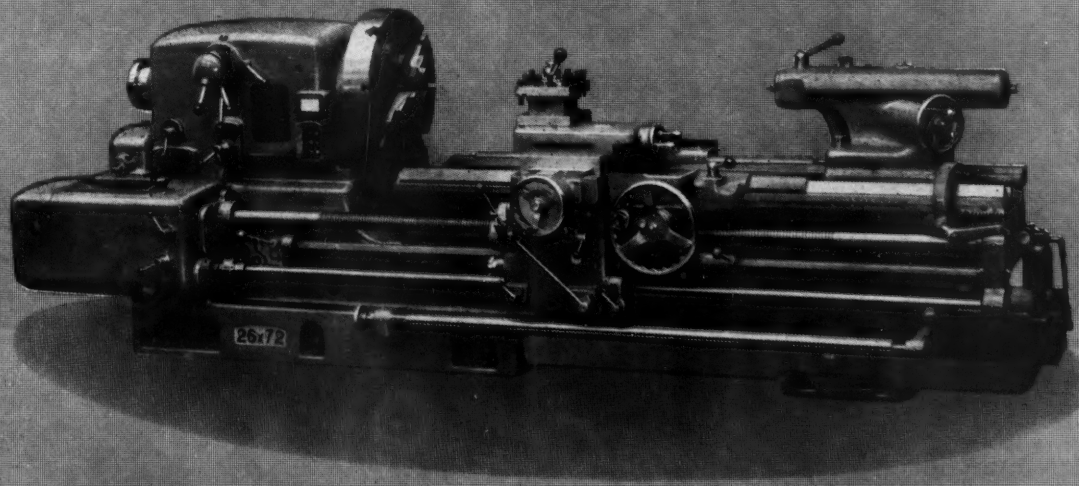
ON 26" and 30" SWING LATHES

Rotation of finger knob on end of apron gives 4 changes to normal feed rate from operators position

Ratios: 1½-1, 1-1, 3-4 & 1-2



DESCRIPTIVE LITERATURE SENT ON REQUEST

Dean Smith & Grace

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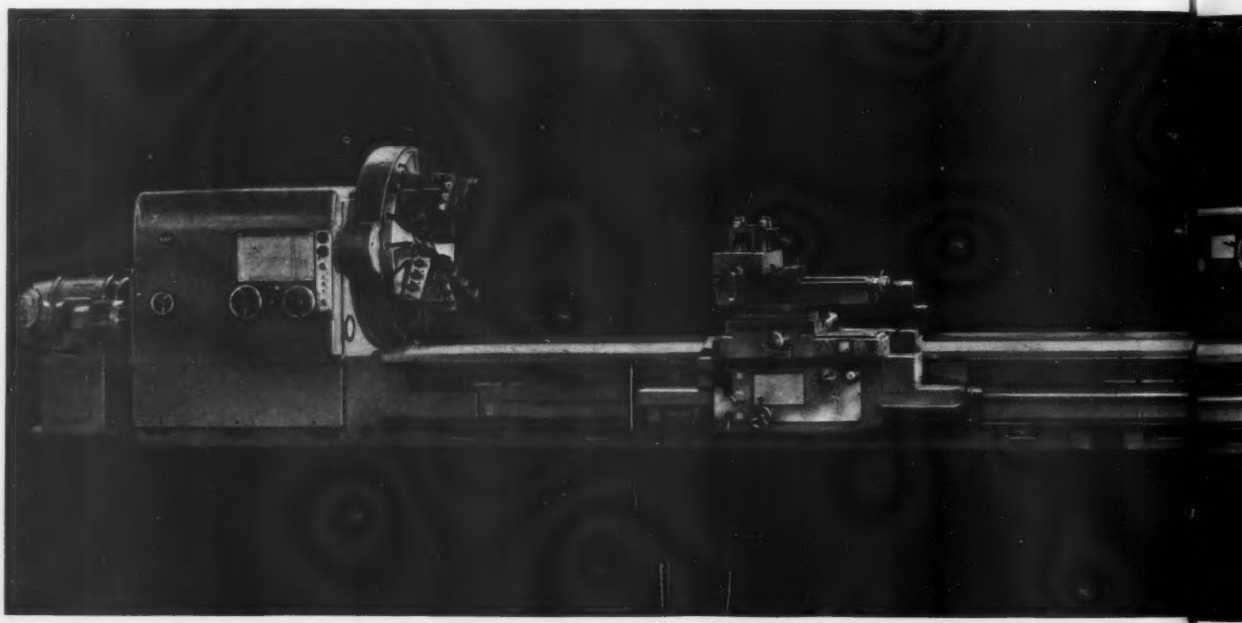
VDF

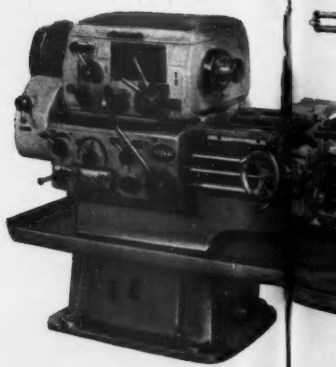
gives you choice

VDF HIGH DUTY LATHE, type E1400 B

- triple bedways
- saddle runs unimpeded past rests and tailstock
- 24 spindle speeds — 0.9 to 180 r.p.m.
- main drive motor 100 h.p.
- maximum centre distance 394″ swing over bed 58¼″

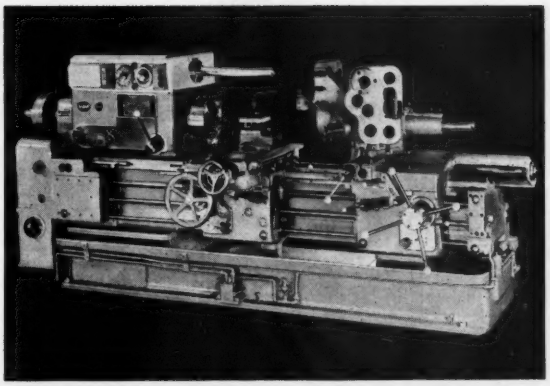


Choice of the finest Continental machine tools in the size and capacity to suit your requirements. Turret lathes, high speed precision lathes, copying lathes, standard and heavy duty centre lathes, planing machines — these are a few of the wide range of standard and special-purpose VDF machines, each available with a complete selection of extra equipment. Contact Sykes Machine Tool Co. Ltd. now for details of the machine you want in the size you need.



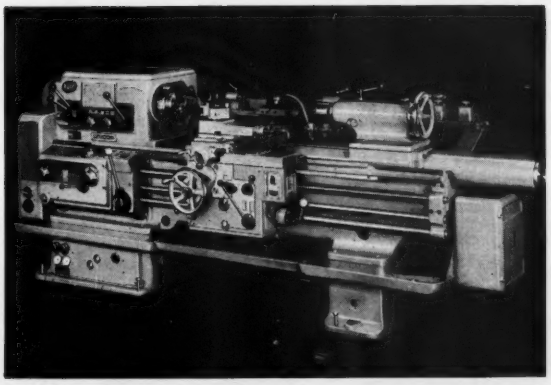
VDF TURRET LATHES, type RS

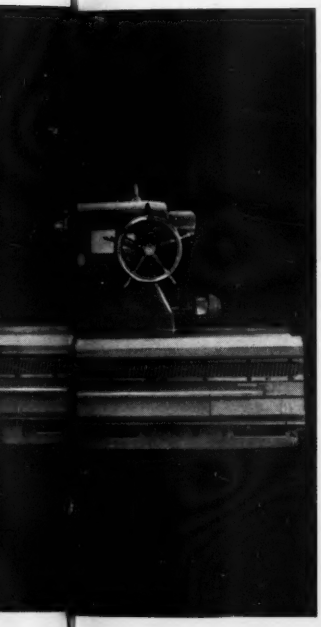
- fitted with pre-selector system for increased production
- feeds, speeds, direction of rotation, instantaneous stopping all programme controlled
- four models available with capacities up to 4″
- hardened & ground bedways and rapid traverse in all directions
- swing over bed up to 22 1/16″ — 19 h.p. motor



VDF UNICOP COPYING LATHES, type 1

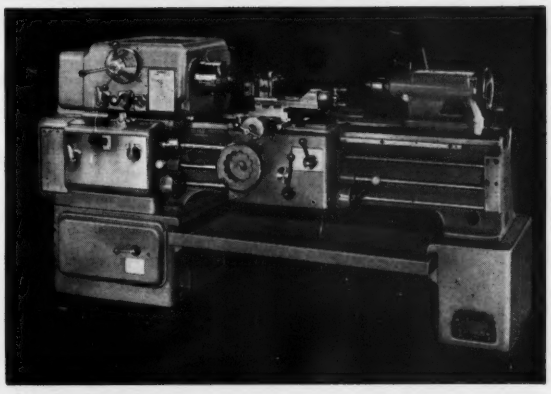
- for normal *and* copy turning
- ideal for workshops where single-purpose copying lathe is uneconomic
- electronic — hydraulic and ultra sensitive
- normal copying traverse up to 29½″ and cross slide to 5″
- three types available

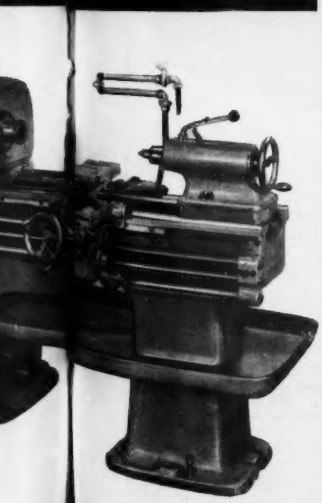




VDF LATHES, types 36 and 44

- extremely versatile, with high degree of finish
- 30 spindle speeds from 11 to 2240 r.p.m.
- three models available with swing over bed up to 18″ and centre distance up to 118″





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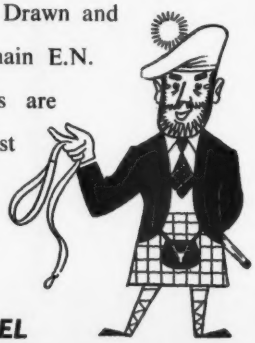

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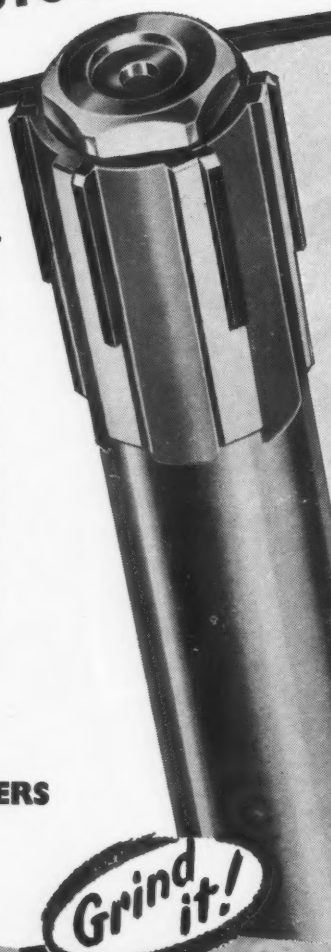

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The Institution of Production Engineers Journal
VOL. 37 No. 8 AUGUST, 1958

1960 Associate Membership Examinations Exemptions

IN the Institution's Journal for March, 1958, were published particulars of the new Associate Membership Examination which comes into force during 1960. As from that date, all exemptions afforded under the old examinations are cancelled but in order that this shall not impose undue hardship, applications for Graduate membership based on old regulations will receive sympathetic consideration until the end of 1962, if a suitable course is now being studied.

In considering exemptions, due regard has been given to the fact that facilities for the study of some subjects to the high academic level demanded by the Institution's examination are not yet universally available, although such provision is growing rapidly. Consequently many able men have been forced to follow academic studies not designed for production engineers, although they eventually enter the production engineering profession. Here, by dint of much personal application, they may eventually achieve considerable success. Having proved their worth in this way the Institution is prepared, for the time being, to accept from them certain other academic qualifications in lieu of its own examination, or parts thereof, when these men apply for corporate membership, *provided that they hold or have held adequate managerial status on the production side of industry.* A list of the qualifications at present approved is given in the Appendix hereto.

It should be borne in mind that the Institution embraces qualified production engineers engaged in all branches of manufacturing industry and is not confined to those concerned with metal working. Furthermore, these lists are not necessarily complete. If any person or body feels that some other qualification should be included, they are invited to forward particulars thereof to the Institution's Education Officer for consideration.

QUALIFICATIONS AFFORDING EXEMPTION FROM THE WHOLE OR PARTS OF THE 1960 EXAMINATIONS

In considering the award of exemptions, there are two guiding principles of policy :-

1. The academic standard, and the volume, of the material or qualification offered to obtain complete or partial exemption shall not be lower than the whole or the relevant part of the Institution's examination.
2. In applying the foregoing condition (1), the criterion shall not necessarily be " subject for subject " but " part for part ", thus :
   (a) Basic science should approximate to the requirements of Part I.
   (b) Applied science should be the equivalent of Part II, particularly bearing in mind that at least one-half of the contents of this part are concerned with the application of science to production technologies. The production technologies offered, however, need not be concerned with metal working but may refer to production in any type of industry. The requirement of production content is fundamental.
   (c) The quality and quantity of Management Studies offered should be equal to the requirements of Part III.

A. Exemption from Parts I, II and III

A1 Diploma in Technology (Eng.) in PRODUCTION ENGINEERING, gained at:

Birmingham College of Technology
Loughborough College of Technology
Northampton College of Advanced Technology (London)
Wolverhampton and Staffordshire College of Technology

A2 First degree in PRODUCTION ENGINEERING of:
Manchester University

A3 First degrees in ENGINEERING or APPLIED SCIENCE, together with the post-graduate course in PRODUCTION ENGINEERING of:
Birmingham University
London University — Imperial College

A4 Higher National Diploma in PRODUCTION ENGINEERING gained at:
Gateshead Technical College

A5 Diploma in AIRCRAFT ECONOMICS AND PRODUCTION of:
College of Aeronautics, Cranfield.

Diploma in METALLURGICAL WORKS ENGINEERING of:
Loughborough College of Technology

B. Exemptions from Parts I and II

B1 First degree in CHEMICAL ENGINEERING of the Universities of:
Birmingham ; London — Imperial College ; Manchester ; Sheffield (Fuel Technology and Chemical Engineering) ; Durham ; Leeds ; Edinburgh.

B2 First degree in METALLURGY of the Universities of:
Birmingham (Industrial Metallurgy degree only) ; London — Imperial College ; Manchester ; Durham ; Leeds (Degree "A" only) ; University College of Swansea.

B3 First degree in MINING of the Universities of:
Birmingham ; Sheffield ; Durham ; Nottingham ; Edinburgh.

B4 First degree in TEXTILES of the Universities of:
Manchester ; Belfast ; Leeds.

B5 Various first degrees, as shown, of the Universities of:
Birmingham — PETROLEUM PRODUCTION ENGINEERING
Manchester — Ordinary degree in MECHANICAL and PRODUCTION ENGINEERING, if Production Engineering subjects are taken
Sheffield — MECHANICAL ENGINEERING if Engineering Manufacture is taken — GLASS TECHNOLOGY
Durham — MECHANICAL ENGINEERING degree "b" or degree in APPLIED SCIENCE, if either is taken together with the certificate in Production Engineering
Leeds — GAS ENGINEERING
University College of Swansea — CHEMISTRY

B6 Higher National Diplomas, if PRODUCTION ENGINEERING subjects are taken, gained at:
Borough Polytechnic (London) — Mechanical/Production
Dagenham Technical College — Mechanical
Enfield Technical College — Mechanical/Production
Leicester College of Art and Technology — Mechanical

B7 Higher National Certificate in PRODUCTION ENGINEERING together with O.N.C.'s which include the subject of Production Processes, will be accepted on a subject-for-subject basis, if conditions laid down in the Institution's memorandum E.M.62/E are met.

C. Exemption from Part I and Group A of Part II

C1 First degrees in CIVIL, or ELECTRICAL or MECHANICAL ENGINEERING of the Universities of:

Belfast ; St. Andrews ; Birmingham ; London — Imperial College ; Leeds ; Sheffield ; Durham ; Nottingham ; Southampton ; Cambridge ; Glasgow ; Edinburgh ; University College of Swansea ; London — External degrees.

C2 First degrees in CIVIL ENGINEERING of the Universities of:
Liverpool ; Bristol.

C3 First degrees in ELECTRICAL ENGINEERING of the University of:
Manchester

C4 First degrees in MECHANICAL ENGINEERING of the Universities of:
Manchester ; Liverpool.

C5 First degrees in AERONAUTICAL ENGINEERING of the Universities of:
Belfast ; London — Imperial College ; Southampton ; Cambridge ; Glasgow.

C6 First degree in METALLURGY of the Universities of:
Birmingham ; Nottingham.

C7 First degree in MINING of the Universities of:
London — Imperial College ; Cambridge ; Glasgow.

C8 First degrees in MINERAL DRESSING of the University of:
London — Imperial College

C9 First degrees in ELECTRICAL POWER and in ELECTRONIC ENGINEERING of the University of:
Liverpool

C10 Diploma in Technology (Engineering) in MECHANICAL / PRODUCTION ENGINEERING gained at:
Welsh College of Advanced Technology

C11 Diplomas in Technology, gained in Colleges listed by the National Council for Technological Awards, in:

Engineering — CIVIL, ELECTRICAL, MECHANICAL, CHEMICAL, AERONAUTICAL

Science — APPLIED PHYSICS, APPLIED CHEMISTRY, CHEMICAL TECHNOLOGY

Mathematics — APPLIED, APPLIED TO ENGINEERING

D. Exemption from Part I only

The Institution has been notified that its application to participate in The Engineering Institutions' Examination for Joint Part I, has been granted, and in 1960 and onwards, we join the Institutions of Civil, Mechanical, Electrical, Municipal, and Gas Engineers, the Institute of Marine Engineers, and New Zealand Institution of Engineers for common examinations for the Part I subjects of English, Mathematics, Applied Mechanics, Engineering Drawing, Heat, Light and Sound, and Principles of Electricity.

Additionally, however, to complete the Institution's Part I requirements, there must be taken either Production Processes or Chemistry, for which examination papers will be set by the Institution.

The Institution's Education Committee has under active consideration exemptions appertaining to Part I.

E. Exemptions from Part III only

E1 Post-graduate courses in PRODUCTION ENGINEERING, successfully completed at :

Birmingham University
London University — Imperial College

E2 Full-time courses in MANAGEMENT STUDIES successfully completed at :

Loughborough College of Technology

F. Partial exemption from Part III

Partial exemption on a subject-for-subject basis is afforded where MANAGEMENT subjects are taken in the following :-

F1 Various first degrees, as shown, of the Universities of :

Cambridge — AERONAUTICAL, CIVIL, ELECTRICAL and MECHANICAL ENGINEERING

Durham — MECHANICAL ENGINEERING. CERTIFICATE IN PRODUCTION ENGINEERING

Edinburgh — ENGINEERING. CHEMICAL TECHNOLOGY

Glasgow — AERONAUTICAL, CHEMICAL, CIVIL, ELECTRICAL and MECHANICAL ENGINEERING. MINING

Leeds — MECHANICAL ENGINEERING

Manchester — MECHANICAL ENGINEERING

Nottingham — MECHANICAL ENGINEERING. METALLURGY. MINING

Sheffield — MINING

F2 Higher National Diplomas as B6 above, gained at :

Enfield Technical College
Leicester College of Art and Technology

F3 Intermediate and Final Diplomas of the British Institute of Management

APPENDIX

Qualifications accepted IN LIEU of parts of the 1960 examinations from candidates for CORPORATE MEMBERSHIP who hold or have held adequate managerial status on the production side of industry.

G. In Lieu of Parts I and II

G1 Corporate Membership, by examination of the :

Institution of Chemical Engineers
Institution of Civil Engineers
Institution of Electrical Engineers
Institution of Gas Engineers
Institution of Mechanical Engineers
Institute of Metallurgists
Institute of Physics
Institution of Structural Engineers
Plastics Institute
Royal Aeronautical Society
Royal Institute of Chemists
Textile Institute

In addition to the qualifications listed above as affording exemption or acceptable in lieu, the Education Committee have many others under active consideration. As they are resolved, they will be published in the Journal.

Air-operated Equipment

by N. P. WATTS

A Paper presented at the Compressed Air Conference, Cornwall, in April, 1958

Mr. Watts, who is Sales Manager of Benton & Stone Ltd., Birmingham, has been associated with The Institution of Production Engineers since 1945, *as an Affiliated Representative. He has given a number of lectures on the subject of compressed air and its uses, to various Sections of the Institution in many parts of the United Kingdom.*

THE last war, like all its predecessors, speeded the development of many ideas and devices which changed all our lives and it is true to say that on both sides of the Atlantic the development of standardised pneumatic cylinders and control gear was stimulated by the most urgent need to secure increased production from existing plant. Extra production was needed immediately — a week one way or the other might make all the difference — and any experiment was worthwhile if there was a chance of obtaining that extra 10% or 20% from machine and operator. It was better still if a skilled operator could be relieved by one unskilled, or one operator could tend two or more machines. Money only could not buy all the production we wanted, but good ideas and intelligent observation very often could and did.

More than a decade has passed and still the need is with us for increased and more economical production. Opportunities are, and will be, numerous for the lively company to meet world-wide competition while, nearer at home, we shall soon be faced with the fierce, down-to-earth competition which will result from the establishment of the European Common Market. More specialisation is required which will give us the opportunity of better tooling to produce improved goods at lower cost and, finally, the vigorous sales endeavour to secure the orders from a market springing from a population of something like 240,000,000.

Only by meeting this situation squarely can we maintain our present standard of living, but by a little extra effort we have also the opportunity of improving this standard. I suggest that pneumatic equipment can help extensively in Britain's productivity, for an extremely low capital investment — plus ideas from everyone remotely concerned with production.

It is an everyday event for those in the industry of supplying pneumatic components to hear that a purely nominal amount of money (20s. to £20) spent on pneumatic equipment, plus a simple idea, has resulted in output being stepped up by any figure from 10 to 1,000%. In practically every factory in

the country this increased potential exists — it is only a question of raising enthusiasm to germinate the ideas.

The main applications of cylinders and control valves in metalworking factories are being dealt with regularly in the technical press, although there are many factories where the value of even the most simple applications has not been appreciated. The following are some of the reasons why management should consider the wider use of air appliances in their factories:

1. A large increase in production can be achieved for low capital expenditure. Old machines can be converted to semi or fully-automatic special purpose units to give production rates comparable to expensive new machines.

2. The increase in speeds and feeds has resulted in handling time normally representing the greater proportion of the total time cycle. It is only here, therefore, that appreciable savings can be achieved. Air operated locating, clamping and ejection devices were the early examples of pneumatic power in machine shops and the demand for equipment for this use led to the development and manufacture of the standardised components which are available today.

3. The use of cylinders to provide a means of remote control of clutch mechanisms, safety guards, directional control of conveyors, feeding workpieces into position, etc., has brought about the need for interlocking one movement with another. Complete machines, and more especially mechanical handling devices, are now powered exclusively by compressed air, partly because of the ease with which interlocking is possible pneumatically, and show a reduction in original cost and maintenance charges. In addition, new designs are made a practical proposition only by the incorporation of air cylinders as the power units.

4. A pneumatic cylinder in conjunction with a hydraulic check cylinder is a convenient method of applying power to feed cutting tools at accurately controlled speeds, with the possibilities of quick approach and rapid return. Practical examples are found on drilling machines, milling machines and capstan lathes — resulting not only in an improved floor-to-floor time, but very often enabling one operator to tend two machines.

5. Responsibility and fatigue are removed from the worker because he has only to move a simple lever or touch a button, after which all movements are made at predetermined speeds and pressures. Production rate is more constant throughout the working day, the finish of the component is often improved, and the workman certainly goes home less tired. There is also the fact that tool life is very often increased.

6. Finally, compressed air is not an expensive power medium — unless it is wasted — and it is unfortunately true that in many plants it is more normal to hear the " fizz " of escaping air than otherwise. The trouble is that many leaks are audible only when the machinery is shut down and then only the cleaners hear this most expensive noise. Good preventative maintenance on all compressed air equipment, pipe lines and the compressor itself, pays handsome dividends and those who complain of the high cost of providing the service should remember that leaks to the equivalent of a $\frac{1}{8}$-in. diameter hole in an air line running at 100 p.s.i. may waste air to the tune of about 25 cu. ft. per minute. By comparison, a 2-in. bore double acting cylinder with 1-in. stroke could be operated over 900 times for the same consumption of air.

   In the same vein it is more than usual to instal a new piece of air-operated plant to run directly off the main air line, which may be set at say 90 to 100 p.s.i. It is more than likely that this new device will operate quite satisfactorily at 80 p.s.i. or at even lower pressures. A pressure reducing valve fitted to each machine and set intelligently will save its cost over and over again and, in any case, the machine will work more reliably if the fluctuations in the normal shop air line are levelled.

   Many users of compressed air complain of the presence of excess quantities of water condensate in their pipe lines, which reduces the efficiency and life of equipment and in many cases causes unpleasant conditions for workpeople. Most of this trouble stems from the absence of, or the insufficiency of, after-cooling facilities. It is no economy to believe it is possible to dispense with an after-cooler of adequate capacity together with the availability of supplies of coolant. Compressor manufacturers will always recommend the correct installation, but good maintenance is important too.

A 200-ton crank press has all its controls air-operated, as indicated in Fig. 1, and for very good reasons. Firstly, the physical effort required to depress the clutch pedal not only reacts against the owner in that a man plainly dislikes the heavy job, but also when that operator is slightly tired he tends NOT to drive the pedal down in the positive manner required, resulting in the clutch key being " nibbled " away. Air-operation ensures that the pedal is moved smartly, at a predetermined speed, to its maximum travel and the special impulse circuit precludes a repeat operation of the press, even though the foot pedal be maintained in the depressed position for an indefinite period. Thus complete protection is afforded both to operator and tools.

The hand valve opens and closes the air-operated vice and simple interlocking ensures that this must be closed before air is supplied to the foot valve which controls the press movement. Thus a large machine with heavy movements is provided with finger light controls.

Fig. 1. A Taylor and Challen 200-ton press, showing air controls for vice and clutch operation.

Another company also employ standard pneumatic units to control their presses and it is quite usual, in addition, to fit air-operated ejector mechanism. Fig. 2, however, shows a 6-in. bore air cylinder being employed as a type of " air spring " to neutralise the weight of the slide and thus relieve bearing load and float and considerably lengthen the effective life of this H.M.E. crank press. The air pressure is adjusted to suit exactly the weight to be supported and an expansion chamber is provided to maintain constant pressure. Pneumatic cylinders are often employed as tensioning devices and of course operating costs in terms of compressed air are practically nil, because little air is lost from the system. The guard on this machine is foot-controlled, the final closing movement operating a control valve which in turn actuates the clutch operating cylinder.

handling of swarf

The handling of brass swarf at my company's works has been a problem for many years. Between five and six tons have to be handled every week and, while it is difficult to improve the method of actual collection from individual machines, a big improvement has recently been made at the dispatch bay.

Previously, after the swarf had been centrifuged, it was stored to await collection in a ground level bin. On arrival the collecting vehicle spent approximately two hours in the works to enable three men to load six tons of swarf. Now, after centrifuging, the swarf is loaded directly — via a hoist mounted on a runway — into a skip which in turn loads the hopper, as illustrated in Fig. 3. The vehicle to be loaded moves under the hopper, a 3-in. bore air cylinder opens the hopper doors, while air vibrators on the hopper walls ensure the downward movement of the material. Including all formalities, paperwork, etc., the vehicle is now on the premises for 15 minutes while the actual time of loading is five minutes. The swarf collecting company are the main beneficiaries of this installation, but their saving is passed on by the payment of a substantially better price for the swarf.

The hopper door control valve is situated in a locked cabinet to prevent accidental discharge and a separate valve is provided for the vibrators.

Other economies include the saving of valuable floor space, and the reduction of handling to an absolute minimum although it is difficult to assess the value of not having to provide for the casual services of three labourers who previously shovelled the swarf. The installation is, of course, a variant of the Parker Plant for aggregate and bitumen weighing.

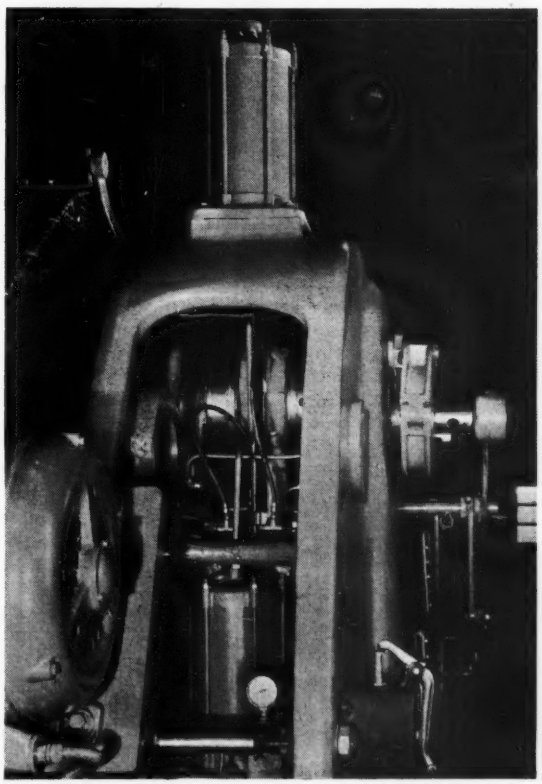


Fig. 2. H.M.E. crank press showing 6 in. bore cylinder for neutralising weight of slide, with expansion chamber located at bottom of photograph.

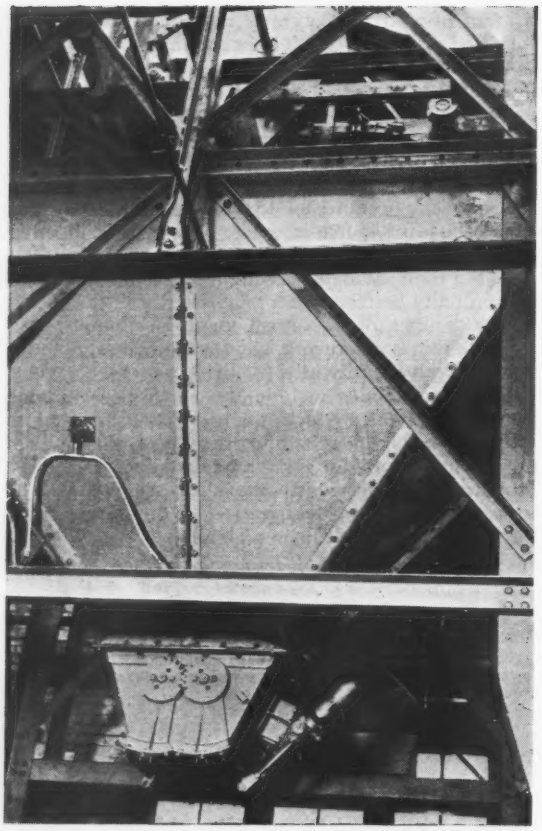


Fig. 3. Air-operated hopper door on swarf handling plant.

At the same works the tool room and experimental shops have found a use for air cylinders, coupled with hydraulic check cylinders, for powering the movement of the tailstock body of hand turning and centre lathes. Fig. 5 shows two midget push button valves, each controlling the movement in one direction of the tailstock of a hand turning lathe. Up to six hand tools may require to be used, each of which may need the individual adjustment of the tailstock position which previously necessitated a rather awkward and heavy hand-operated movement. This fitting on a relatively light type of machine may be considered as a somewhat unnecessary refinement, although the benefits are much appreciated by skilled tool room operators. On larger and heavier machines the benefits are much more obvious.

Pneumatic vices are most useful as general purpose fixtures and the simple conversion of a standard hand operated 3-in. Abwood vice is shown in Fig. 4. Two $1\frac{1}{2}$-in. bore cylinders, through a system of levers, produce a clamping pressure at the jaw faces of approximately 560 lb. from an air line pressure of 80 p.s.i. The vice can still be operated and is actually set by hand and is useful for many drilling and assembly operations. The jaws are not self-locking, however, which is a requirement for most milling operation fixtures.

Fig. 4. Standard 3 in. vice converted to air operation by two $1\frac{1}{2}$ in bore cylinders.

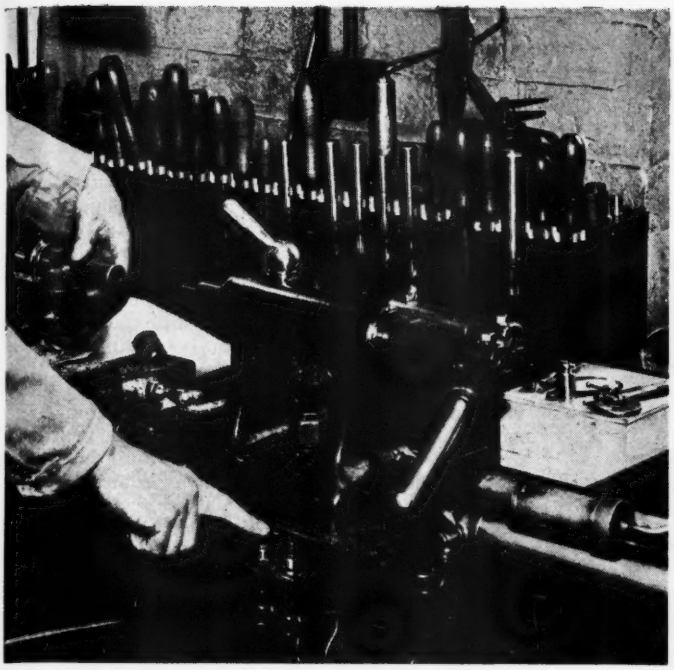


Fig. 5. Air/hydraulic controlled feed for tailstock movement on hand turning lathe.

assembly problems

Much attention has been given to air-operated clamping, machining, forming, riveting and staking operations, but assembly problems deserve equal study. We find so often that the tendency is to concentrate effort on making components more quickly and more cheaply and to overlook the importance of subsequent handling, such as inspection, assembly, labelling, marking and packing. The following example at a Hertfordshire radio factory indicates that, although the problems may be more troublesome to solve, the results may easily produce higher rewards. This Company have recently installed an automatic tag panel assembly machine which is completely air-operated. Previously, tags were inserted singly by hand and clenched in a hand-operated fixture with a maximum output of two per minute.

On the new machine, tags in the form of continuous coiled strips (Fig. 6A) are fed from storage drums and inserted by means of a die through the panels, which are fed into position from the vertical magazine by an air-operated 24-position rotary feed table. They are twisted for retention purposes and then sheared off (Fig. 6B). In order to ensure correct clearance a sizing cylinder engages a plunger between tags, after which the component is ejected down a chute. Output, including stoppages, changing plates, dies, etc., is 30 component per minute — an increase of 1,500% over the previous method.

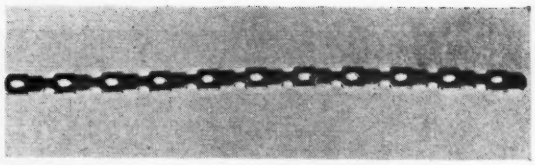


Fig. 6(a). Terminal tags in strip form.

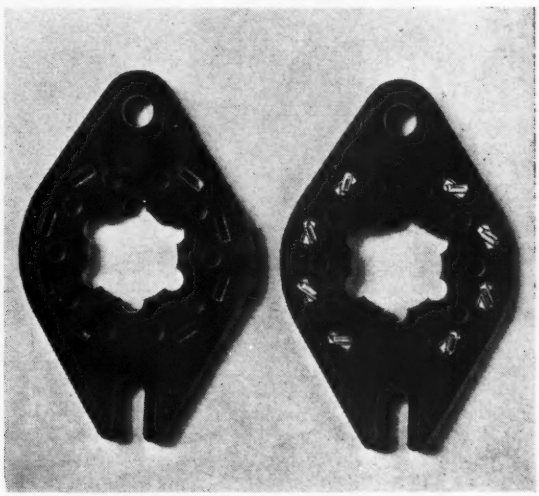


Fig. 6(b). Tag panel only. Panel assembled with tags showing twist for retention on right of photograph.

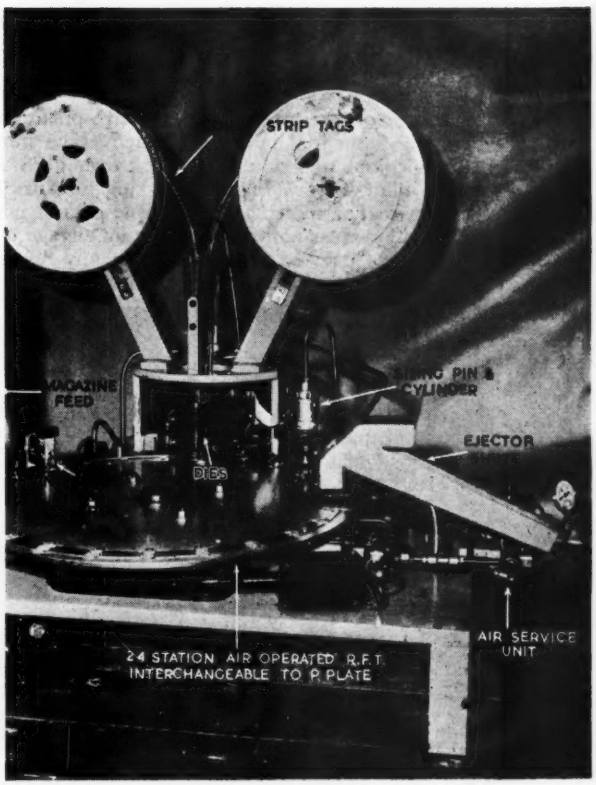


Fig. 6(c). Front view of assembly machine, feeding tags in strip form, shearing, inserting and twisting tags in panels, which are hopped fed on to air-operated 24-station rotary feed table.

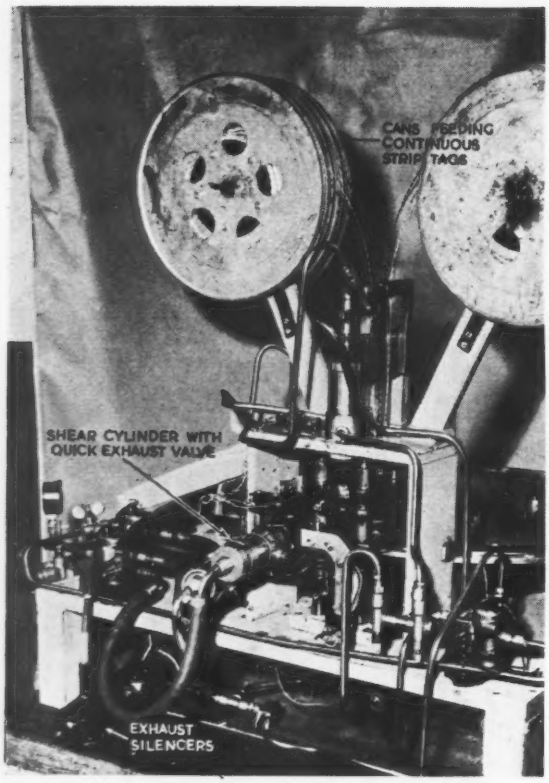


Fig. 6(d). Rear view of assembly machine, showing shearing cylinder and air silencers in foreground.

The control system is entirely electro-pneumatic, employing sequential operation; that is, each movement on completion signals the next through 8 volt solenoid pilot valves. Full interlocking facilities are provided in that the rotary feed table cannot index until tools are clear and the tools cannot engage until the table has indexed. The failure of any function causes the entire machine to stop. Finally, when the magazine becomes empty, a " no-panel " STOP device halts the machine.

high versatility

The machine has a high degree of versatility in that a range of panels may be assembled (e.g., 8 or 12 tags, etc.) merely by changing the top plate of the rotary feed table, the die assembly and the magazine.

Fig. 7 shows a cardboard tube ring cutter — a fully air-operated machine — with safety guards removed to show working parts. The controls are grouped in a cabinet and consist of two hand/air-pilot operated valves and two press buttons for controlling two 8-volt solenoid operated valves. The mandrel is rotated by an electric motor mounted at the far end of the machine, the bearing at this end being the sole support during loading. At this stage the two front half-shell bearing support arms which constitute the tailstock have been lowered by the two associated $2\frac{1}{8}$-in. bore air cylinders. These are shown in the foreground of the photograph in the up position.

The cycle of operation is as follows:

1. With tailstock arms down, a tube — precut to length — is manually fed on to the open-ended mandrel. The left-hand valve is operated to reverse the air in the tailstock arm operating cylinders, which raise the half bearings into their working position. At the completion of this movement, a relay valve is automatically operated and actuates two $1\frac{1}{2}$-in. bore cylinders, driving a locking pin into each arm.

2. The upper push button is touched, thereby energising the two solenoid valves which feed air to the front ends of the four 3-in. bore trunnion mounted cylinders — two situated on each side of the machine. These cylinders straighten the toggles which pivot the knives into the tube for the cutting operation. At the same time an air operated switch starts the electric motor, rotating the mandrel and tube.

3. When the operator sees that the parting off has been completed, he presses the lower push button, reversing the solenoid valves. The knives are lowered and the motor stops.

4. The left-hand valve is then reversed when the locking pins are withdrawn and the tailstock arms lowered.

5. The right-hand valve is thrown and this feeds air to a long cylinder hidden in the frame of the machine, which drives arms the entire length of the mandrel to strip it of the cut rings. At the end of the stripping stroke a pilot valve is automatically opened, which reverses the hand/pilot operated valve and returns the stripper drive cylinder.

In order fully to understand this circuit, it is important to note that, while the air pilot cylinder on the right-hand (stripping) control is used to reverse the valve AND to interlock the circuit, the air pilot cylinder on the left-hand control is employed for interlocking only. It is impossible (*a*) to move the stripper control while the tailstock is up and (*b*) to lower the tailstock arms while the knives are in the cutting position.

A third interlock makes the press buttons ineffective until tailstock arms are up and locking pins in position. Since air is also employed to operate the motor start switch, it follows that the motor cannot be started until arms are up and knives are moving.

The machine provides an interesting example of the use of a toggle to give a rapid approach stroke at low power, followed, as the toggle approaches the straight position, by a slower movement developing greater thrust. Over-travel is impossible; if the toggle, due to incorrect setting, is allowed to go over centre the

knives will withdraw instead of biting into the mandrel as they would with a simple lever action. An increase in production exceeding 250% is achieved by this machine, compared with its predecessors. Physical effort has been entirely eliminated except that required for loading, but perhaps most significant of all from the point of view of management is the increased life of the somewhat fragile cutter knives; the quality of the product is improved and rejections are negligible.

Practically every form of transport, whether it be road, rail, air or sea, employs pneumatic devices and perhaps the best known everyday examples are found on the London Transport trains, where doors open and close tens of thousands of times per day without trouble on both trains and elevators. Air- or vacuum-operated brakes, electro-pneumatic signalling systems, are the order of the day and it is difficult to imagine an alternative way of applying power should it become, for some reason, impossible to use compressed air.

In the field of aviation, compressed air equipment of specialised design has for many years found favour and the Dunlop system, fitted on the new Fokker "Friendship" aircraft and working at pressures of 1,000 p.s.i. and over, is the worthy successor to some of the old equipment which operated at just over 100 p.s.i. Wheel brakes, undercarriage, locking and interlocking devices, nose, steering, wing flaps and engine radiator flaps can all be satisfactorily worked by compressed air. Higher air speeds have required changes in aircraft shape, resulting in less space for increasing sizes of power plant and fuel capacity and the need for a greater complexity of services requiring power for operation.

There are three main sources of power for operating — electric, hydraulic and pneumatic — and all three services are being widely used. In spite of strong rivalry, it would appear that the pneumatic systems certainly win on the count of weight alone and can show a saving of 20 to 30%. Apart from this, small pipe lines can be employed — $\frac{3}{16}$-in. o/d and smaller are quite usual and the elimination of return pipes, oil reservoirs and the fire risk of hydraulic systems makes the pneumatic systems very attractive. The ability to store, in bottles, air at pressures of up to 3,000 p.s.i. is useful in that this reserve of power can be used, for instance, at take off for raising the undercarriage. Investigation in one case has shown that a hydraulic or electric system would demand about 27 h.p. from the engines at this critical point while the pneumatic system, taking advantage of stored energy, required only 3·6 h.p. Adequate receiver capacity in an industrial undertaking can also contribute to reduced costs and maintenance. Ground charged pneumatic systems are also being used extensively in the new field of guided missiles, for operating launching, propulsion and guidance mechanisms.

The possibility of opening doors and windows has also been tapped and installations are to be found, for instance, in ships and electricity generating stations, where windows are usually fairly inaccessible. In countries of rapidly changing climate it is often desirable to close all windows at extremely short notice, to protect valuable plant from damage by dust and sand storms which arrive without warning.

On the generating plant, too, pneumatic powered devices are in evidence and Fig. 8 shows a typical air-operated single nozzle soot blower, such as might be fitted to the boilers of any steam-raising plant both ashore and in many famous ships of the merchant and

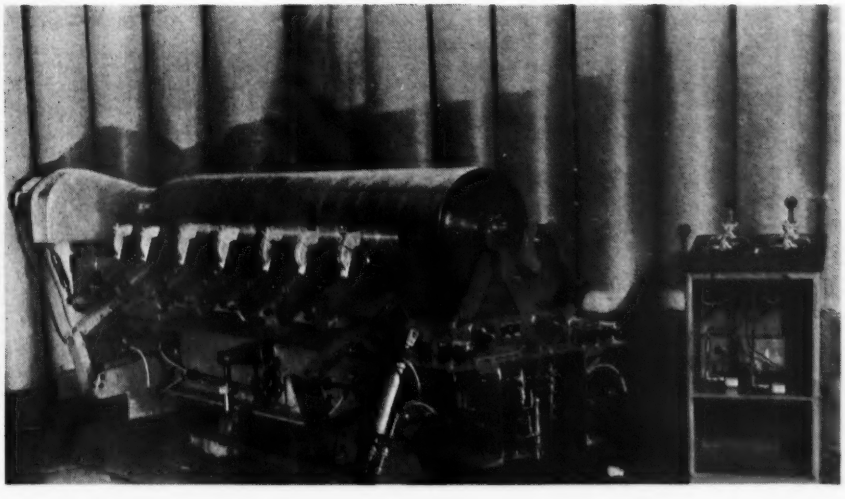


Fig. 7. Perkin cardboard tube ring cutter with all movements pneumatically-operated, including motor starting with full interlock protection.

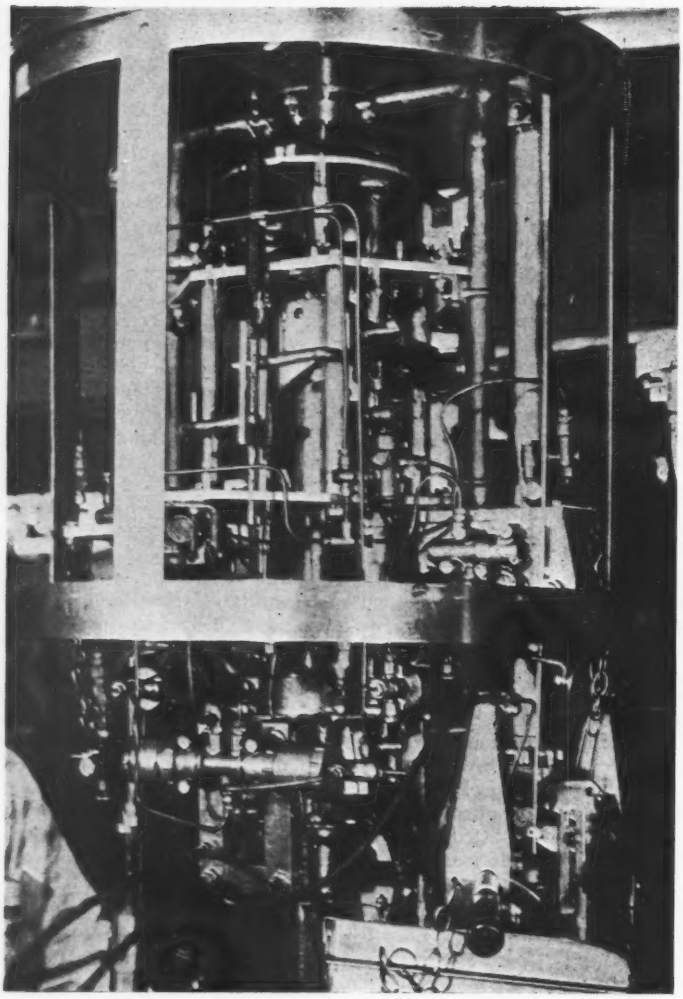


Fig. 9(a). Dawson automatic "rotating" bottle-crater and decrater, showing valve controls. Gripping head appears in right foreground.

fighting navies of the world. The adoption of pneumatic operation has resulted in the simplification of the controls on this device, which basically consists of a uni-directional air motor driving through reducing gears and a mechanical reversing device to produce a reciprocating action. Steam is used for blowing accumulated soot from the boiler tubes and working conditions are arduous. Pneumatic control valves make possible the remote operation of any number of blowers from one central panel and a choice is normally offered of blowing all boilers in sequence, in sequence skipping any selected number, or individually with the full protection that one blower, having commenced, must complete its cycle before another can follow.

Fig. 9 shows a piece of air-operated plant which helps to ensure that our early morning milk arrives regularly and on time. The bottling plant at the model dairy at Morden of The Express Dairy Co. Ltd., handles an average of 2,000,000 milk bottles per day. An operator, using the Dawson crating and decrating machine, removes 240 bottles from 12 crates every minute — picking up, moving across and putting down an average of four bottles per second, with breakages practically nil and with operator fatigue reduced to a negligible amount. Each machine consists of a centre column about which two grab heads rotate, each handling 20 bottles. The grabs are fitted with stainless steel rods, running longitudinally and as the head lifts the rods close in and grip under the rim of the bottle necks. This movement is accomplished by a series of cams. The complete cycle of operations when decrating is (*a*) grip bottle necks; (*b*) lift bottles clear of crate; (*c*) rotate through 180°; (*d*) lower and release bottles on to the bottle conveyor. The rotary motion of the head is accomplished by an air cylinder fixed

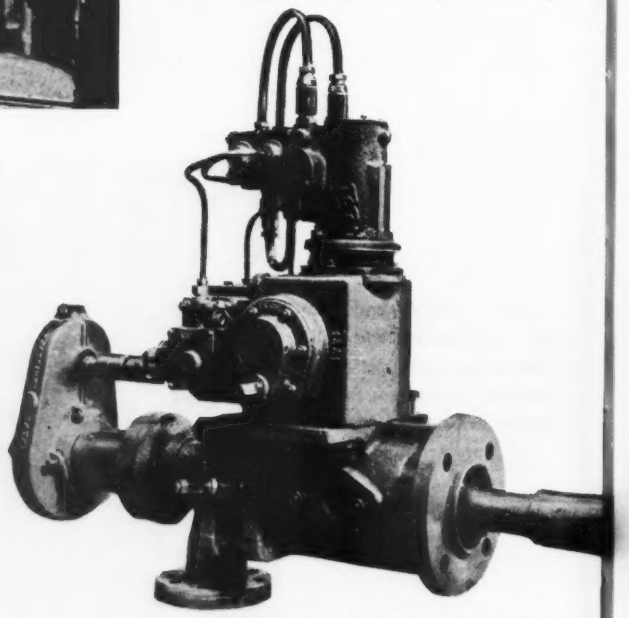


Fig. 8. Clyde air-operated soot blower.

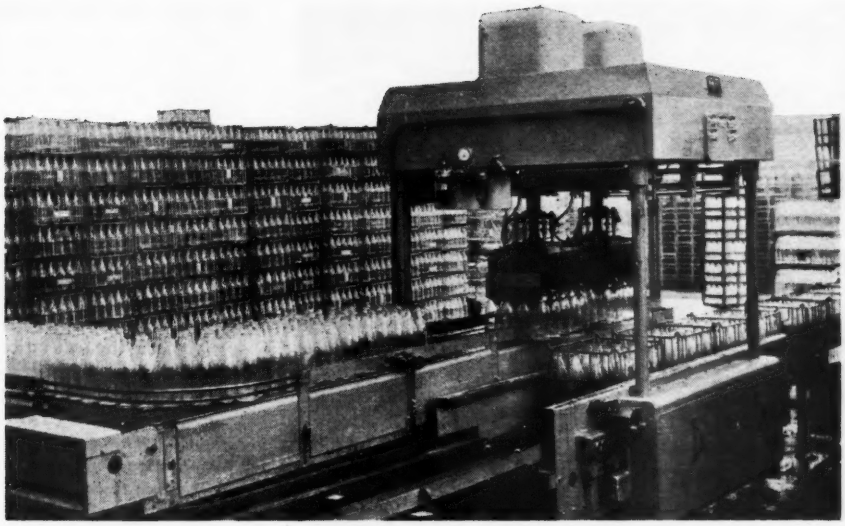


Fig. 9(b). General view of "in line" crater and decrater employing similar air-operated heads.

to the rotary arm which thrusts upwards against a cam fixed to the centre column. Mechanical handling is possibly seen at its best in such plants, and it is always something of a shock to me that all this wonderful plant is dependent absolutely on the humble cow chewing its cud quietly in a field.

While on the subject of cows, an interesting machine is installed at the Hannah Dairy Institute, Ayr, Scotland. It is a type of respirator to pump air or gas into the animal's lungs and employs standard industrial cylinders and valves as shown in Fig. 10. It is an extremely simple piece of apparatus and although the illustration shows the cylinder being driven mechanically, the movement could readily be imparted pneumatically and could thus be entirely independent of electricity, the pneumatic source of power always being readily available in such medical establishments in storage bottles. Successful experiments are also being carried out by the medical profession on similar machines for the treatment of patients suffering from the effects of poliomyelitis. One type of such a machine, described as a volume controlled patient-cycled respirator for adults and developed by the Western Regional Hospital Board in Glasgow, was explained recently in an article by Dr. Greer, appearing in the *British Journal of Anaesthesia*.

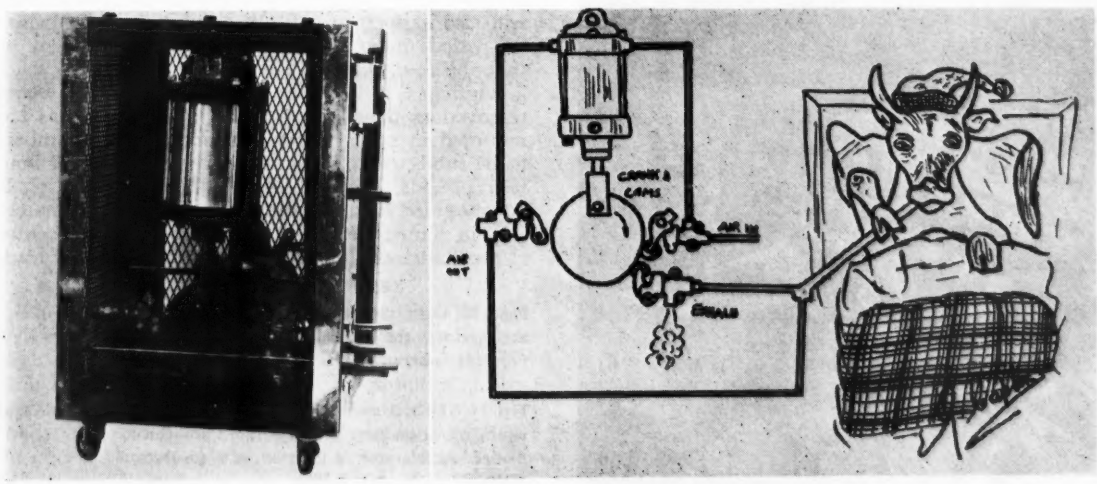
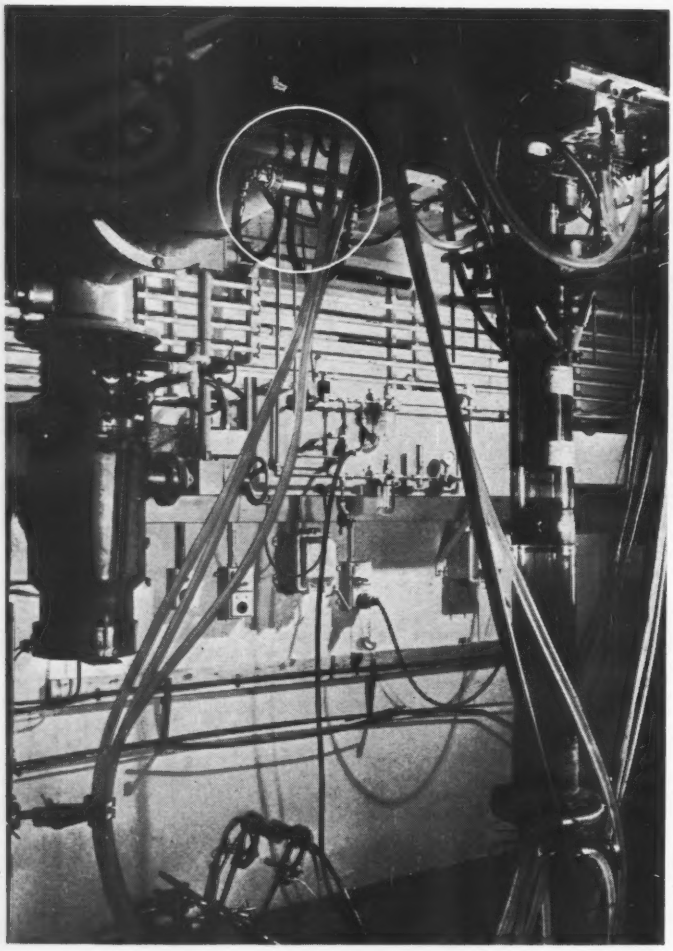


Fig. 10. Respirator for pumping air or gas into cow's lungs.



handling radioactive material

The Atomic Energy Research Establishment at Harwell have found, as might be expected, a number of uses for pneumatic devices for the remote control of equipment, handling radioactive material. At the Medical Research Council's Radiobiological Research Unit at Harwell, standard pneumatic cylinders are employed to open and close the vacuum control valves on the 1,000,000 volt positive ion accelerator. This machine is used for accelerating deuterons reacting with a target of lithium 6 deuteride mounted on a copper disc at the bottom of the glass tube (Fig. 11). At this point neutrons are generated of about three million electron volts energy and the subjects for the radiation experiment are placed at predetermined distances from this point.

An air cylinder operated from the central control panel closes the main vacuum on-off valve should this become necessary for some reason during the test. This isolates the main vacuum pump from possible radio-active effects in the event of any emergency and it is important that the movement is made at the very instant circumstances demand. Pneumatic operation makes this possible. The device is also used for isolating purposes when the targets are changed. The other two vacuum control valves, at present hand-operated, are now being converted to air operation, the object being to enable a complete cycle of operations to be controlled remotely with full interlocking facilities. It is interesting to note that two vacuum pumps are employed. One creating a vacuum of $\frac{1}{10,000}$ part of an atmosphere and the second a vacuum of $\frac{1}{100,000,000}$ part of an atmosphere.

Broad beans (*Vicia fabia*) are the subject of the study of radiation effects on living cells and this research is an important part of the investigation into the effects on human beings. For all practical biological purposes what happens to the cell of a broad bean will also happen to any other living cell. Beans are cultivated under carefully controlled conditions so that the root, with all side shoots removed, reaches a length of 8 to 10 inches, the top green shoots being removed as they form. At this stage the beans are mounted in racks and placed in Perspex chambers to be subjected to radiation, for either short or long term periods, as seen in Fig. 12. The source (Cobalt 60) mounted in an aluminium capsule approximately ¼ in. in diameter and 1 in. long is housed in the centre of a cylindrical bomb with 10 in. thick walls of lead.

Fig. 11(a) (top left). **Million-volt ion accelerator, showing 1½ in. bore cylinder (ringed) operating vacuum control valve.**

Fig. 11(b) (bottom left). **Central panel from which all operations of accelerator are controlled. Accelerator is situated in a separate chamber with wall, ceiling, etc., of suitable material to give protection against radiation.**

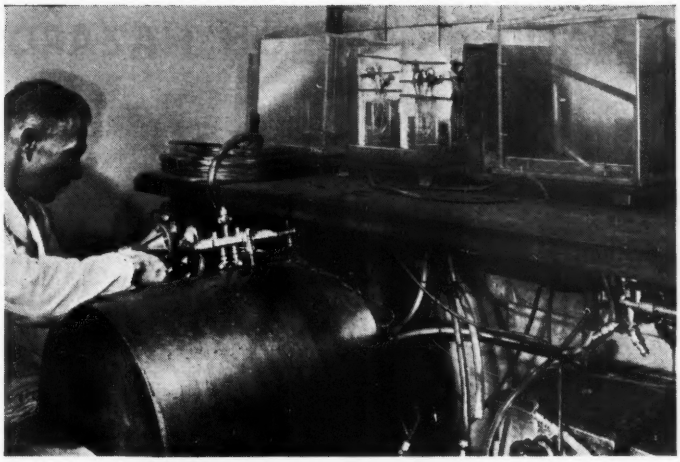


Fig. 12. Broad beans in centre Perspex case mounted for study of radiation effects on living cells. Bomb with 10 in. thick lead walls, containing the Cobalt 60 "source" which is cylindrical and measures about ¼ in. diameter by 1 in. long, can be seen in left foreground.

The outlet port of the bomb is connected by a suitably formed stainless steel tube to the radiation station in the Perspex case. A flow of compressed air pushes the capsule—in effect a loose-fitting piston — along the tube and holds it in place for the desired period, while deoxygenated water is sprayed over the plant. A standard air pilot operated four-way control valve is used, water passing through the main valve and the pilot control being from the main control panel situated behind a concrete screen. Oxygenated water is supplied in between periods of radiation to revive the plant and passes through a second pilot controlled valve. Timing of the cycle is done electronically and the whole process can be fully or semi-automatic, as desired. For those interested, the radiation dose can be between nine and 20 Rontgen per minute.

Here we have another handling problem resolved by a little ingenuity in a most simple, reliable and inexpensive way.

Even our very health, then, benefits greatly from the use of air-operated equipment and the few examples described in this Paper must surely serve to prove that compressed air equipment is one of the most versatile tools which can help our industrial progress. I hope that these success stories will stimulate your thoughts sufficiently to investigate the possibilities in your own fields of activity.

The author wishes to acknowledge with thanks the help and facilities for photographing provided by the following organisations and members of their staff:

Benton & Stone Limited (Including permission to use examples shown in their film "AIR CONTROLLED")	Birmingham
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Express Dairy Co. Ltd.	London
Hordern, Mason & Edwards	Birmingham
Medical Research Council Radiobiological Research Unit	Harwell
W. B. Nicholson (Instruments) Ltd.	Glasgow
Perkin & Co. Ltd.	Leeds
Taylor & Challen Ltd.	Birmingham

N.B.—The tag assembly machine used by Murphy Radio Co. Ltd., Welwyn Garden City, was designed and patented by Newman & Guardia Ltd., of Harlow.

RESEARCH PUBLICATIONS

The Institution is advised by PERA that Dr. G. Schlesinger's book on "Accuracy in Machine Tools: How to Measure and Maintain It" is now out of print and cannot, therefore, be supplied. The following I.Prod.E. publication is, however, still obtainable from PERA at "Staveley Lodge" Melton Mowbray, Leicestershire.

"Practical Drilling Tests" by D. F. Galloway and I. S. Morton. Price 21s.

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FIRE AND EXPLOSION HAZARDS IN COMPRESSED AIR SYSTEMS

by A. C. SMITH, B.Sc. and A. THOMAS, Ph.D., B.Sc.

A Paper presented at the Compressed Air Conference, Cornwall, in April, 1958.

Mr. Smith was educated at Whitley Bay Grammar School and Durham University, where he read mechanical engineering and graduated in 1941. *He completed an engineering apprenticeship with R. & W. Hawthorn, Leslie & Co. Ltd., Newcastle on Tyne, in* 1942 *and subsequently served in the R.N.V.R.*

Since 1946 *he has been employed as a technical assistant in the Lubricants Department of The Shell Petroleum Co. Ltd., London.*

Dr. Thomas was educated at Aberdare Boys' County School and Imperial College. He graduated with honours in chemistry in 1944 *and spent the following six years in the Department of Chemical Engineering and Applied Chemistry, where he carried out research work on the spontaneous combustion of stored oil seeds, and on crank-case explosions. During this time he was awarded the degree of Ph.D.*

Since 1950 *he has been at the Thornton Research Centre of 'Shell' Research Ltd., where he is in charge of chemical research work upon combustion problems.*

MANUFACTURERS of air compressors and associated equipment have achieved a very high standard of safety, and compressed air systems are far from being regarded as dangerous, even where maintenance falls well below the highest standards. Nevertheless, disastrous fires and explosions have taken place from time to time all over the world. An unfortunate aspect of the matter is that, until comparatively recently, enquiries following such incidents have not led to a definitive appreciation of the circumstances in which they are liable to occur. Occasional explosions and fires, or the formation of considerable amounts of carbon monoxide, have continued to take place without apparent warning in systems that had given good service for a long time. In many cases investigation of a fire or explosion has failed to establish the specific cause. Various opinions have been expressed from time to time on the mechanism or mechanisms involved, but little research into the question has been carried out until recently.

Since the War considerable attention has been paid to the origin of explosions in compressed air systems, particularly in France, the U.S.A., the U.K. and Canada. Although the course of events in such accidents does not follow a uniform pattern, an account can now be suggested of the most likely manner in which conditions resulting in an explosion are liable to arise.

An explosion in a compressed air system may, of course, result from mechanical failure of members containing the air — for example, through internal wasting caused by corrosion. The present discussion, however, is confined to the explosion hazard associated with the combustion of inflammable materials within the system. This refers primarily to mineral lubricating oils.

There are three fairly distinct types of incidents that have occurred in compressed air installations: fires, explosions, and detonations. It will be helpful

first to consider how each of these arises, and to see how they are related to each other.

fires and explosions

When an explosion takes place in a mixture of inflammable material and air, what happens in fact is that a flame passes very quickly through the mixture, producing a rapid rise in temperature, and consequently in pressure. It is this rise in pressure that causes damage. If an explosion is to take place, two conditions are necessary: first, there must be inflammable material intimately mixed with air in the right proportion; and second, there must be an appropriate source of ignition. This intimate premixing of air with inflammable material is what distinguishes an explosion from a fire. In a fire the combustible is separate from the air until it meets it in the actual flame, so that the rate of combustion, and consequently of rise in pressure, is limited by the speed at which the two reactants mix.

In its consequences an explosion is more serious than a fire, but fortunately it occurs less frequently. In fact, some authorities consider that many fires on the discharge side of air compressors take place unobserved, since they may have little or no mechanical effect.

Distinctions have been drawn here between a fire and an explosion both in their inception and in their effects, but it should be added that either can lead to the other, given a suitable set of circumstances.

detonations

Very extensive damage has been caused to compressed air pipe lines in a number of serious incidents, particularly at Rossington in this country, and at Béthune and Courrières in France. The characteristics of these explosions differ so much from those of other explosions, that it seems that a distinct, separate process is involved. Charbonnages de France have carried out some extremely valuable work which has thrown considerable light on such incidents and has established that they are due to a process akin to detonation. We are therefore in this Paper segregating them from other explosions of lesser scale, and shall refer to them as detonations.

THE EXPLOSIVE MEDIUM

Let us examine the first prerequisite of an explosion: the presence of an inflammable material intimately mixed with air in suitable proportion.

Lubricating oil is a direct source of inflammable material as vapour, as mist, or as liquid oil on the surfaces of the system. In addition accumulations of oil exposed to oxidation in hot parts of the system form inflammable deposits. Stagnant oil and products of its decomposition are commonly mixed with aggregated matter carried into the compressor at the air intake, the mixture being solid or tarry. The extraneous matter might include combustible material such as coal dust.

The several forms that could be taken by a potentially explosive mixture vary in the circumstances in which they are liable to come into existence, and in the following discussion each will be considered in turn.

oil vapour

This refers to vapour produced directly through volatilisation of lubricating oil, and not as a product of chemical decomposition.

vaporisation of oil; flash point

The possibility of an explosion as a result of excessive volatilisation of the oil has always been recognised. Except at very high air pressures the partial pressure of oil vapour required to support combustion is relatively small. At atmospheric pressure the lower limit of inflammability will be reached with a partial pressure of oil vapour in the range 5 to 10 mm. The boiling range of an oil does not give a very reliable indication of the temperature at which vapour pressures of this order will exist, and it is usual to measure it directly in a flash-point apparatus. The " flash point " so obtained is the lowest temperature at which, under prescribed conditions, the concentration of oil in the vapour phase is sufficient to support combustion. Suitable oils in the viscosity range most often required for internal lubrication of air compressors usually have flash points in the range 380 to 450°F.

The effect of variation in flash point between different mineral oils must be considered. The flash point bears a general relation to viscosity; spindle oils usually have closed flash points of 300 to 350°F, machine oils and engine oils 350 to 500°F, and steam cylinder oils 500 to 650°F. Oils of very low flash point can be disregarded, since the requirements of hydrodynamic lubrication and effective sealing will impose a lower limit of viscosity. Most compressors require oils in the viscosity range 80 to 130 cs. at 100°F, and in most cases such oils should show closed flash points of about 400 to 440°F. If a higher flash point is required the effect is to compel the use of a heavier oil. Values of 500°F or thereabouts imply a viscosity of around 20 cs. at 210°F, which would be at about the viscosity level of an SAE 50 engine oil. Steam cylinder oils would have to be used to obtain flash points higher still. For the average compressor, therefore, oils of high flash point will be unsuitable because of excessively high viscosity.

Apart from the more immediate objectionable effects of excessive viscosity on the performance of the machine, heavy oils are undesirable in that they are especially prone to deposit formation in the delivery system, and usually show comparatively high carbonising tendencies. Since the accumulation of carbonaceous deposits is (as will be discussed later) a potential source of extremely high temperatures, the preference for a heavy oil is very liable to give rise to the trouble it is supposed to avoid.

In respect of flash point, a factor of safety is provided by increase in air pressure, since the partial pressure of oil vapour in a mixture of oil vapour in air at the lower limit of inflammability remains in approximately constant proportion to the total pressure as the latter rises.* Multiplication of air pressures is reflected by corresponding increases in the minimum concentration of oil vapour necessary to support combustion. The effect on flash point — i.e., the flash point at the pressure prevailing, and not the particular value at atmospheric pressure — is however, limited, since vapour pressure rises rapidly with increase in temperature. An oil with a flash point of, say, 420°F will probably have an initial boiling point of about 650°F, i.e., its vapour pressure will increase from say 7 to 760 mm. from 420 to 650°F. At 8 atm. the flash point of such an oil would be around 470°F. With increase to considerably higher pressures flash point will increase further, but it will do so at a rapidly diminishing rate and it would be unwise to assume even at very high pressures an effective value of more than 50°F above that at atmospheric pressure.

In most compressors the designed operating temperatures do not approach the effective flash point of the oil, but in others it would appear that they equal or exceed it. For example, where pressures of about 8 atm. are obtained in a single stage, polytropic compression (assuming $pv^{1.3} = \text{const.}$) from 60°F and atmospheric pressure would give a discharge temperature of 375°F, and adiabatic compression ($pv^{1.41} = \text{const.}$) a discharge temperature of 500°F. Probably the final temperature under such initial conditions would be nearer 375°F, but a point often overlooked is that in practice the suction pressure will probably be sub-atmospheric, and since the discharge pressure is prescribed by the design of the discharge valves this means that the true compression ratio may be considerably higher than it appears to be at first sight, particularly if cleaning of the air intake filter has been neglected. Apart from such marginal cases, numerous compressors designed for intermittent service have been operated with discharge temperatures undoubtedly in excess of the flash point of the oil.

The development of an explosive concentration of oil vapour during operation of the compressor would require sustained evaporation of oil at a rate determined by that of air flow. However, with delivery of air at a substantial rate the quantity of oil necessary to produce a concentration of vapour at the lower limit of inflammability will be far in excess even of the total carried into or injected into the cylinders. For example, in a compressor of capacity 250 cu.ft./min. f.a.d. the weight of air passing through the machine at half load will be about 9·5 lb./min., which would require a supply of oil at about 0·3 to 0·4 pints/min. to produce an explosive mixture, whereas oil consumption would be perhaps 0·001 to 0·005 pints/min. In order that a dangerous concentration of oil vapour should develop whilst the compressor is running, most of the oil vapour would have to come from oil spread over the walls of the system or contained in the deposits. The bare possibility exists that volatilisation of oil might reach a high enough rate under operating conditions to produce an explosive mixture, but in most systems little short of a raging fire could conceivably provide the extremely high rate of volatilisation that would be required. Conditions are least unfavourable to accumulation of oil vapour in the case of a compressor discharging into a closed vessel such as an air bottle, but even here only an extensive fire would be likely to cause sufficiently rapid volatilisation of oil during operation of the compressor. It may be concluded that a dangerous concentration of oil vapour could only arise when high temperatures persist after air flow has ceased or fallen to a very low rate.

Normally the highest operating temperatures at the walls of the system will no doubt be confined to an area close to the delivery valves, and it is to be expected in view of this that after unloading the machine the peak temperature will fall fairly quickly to a value well below the flash point of the oil. Sustained volatilisation of oil deposits in dangerous volume would on the other hand require persistent temperatures, over sizeable areas, of about 450 to 500°F or more. Some gross abnormality is thereby indicated. Leaving out of account the more fanciful explanations, the more likely sources of persistent high temperatures are thermodynamic effects due to malfunctioning of a machine running unloaded, or the prior existence of a fire or of advanced exothermic oxidative reactions in oily deposits. In referring to malfunctioning of an unloaded machine we have in mind, for example, a two-stage compressor unloaded by closing the suction valve, but without provision for unloading the second stage, in which high temperatures could develop through continuous recompression of air passing through a leaking discharge valve. Again, high temperatures could possibly develop in a machine running unloaded through continued pumping at a slow rate and high compression ratio, due to leakage at the suction valve. Other sources of high temperature may perhaps arise from malfunctioning of the compressor, but lie outside this discussion. Fires and oxidative effects in oily deposits are considered later.

oil mist

During an oil explosion, oil at the instant of reacting with oxygen must be in the vapour phase. It is not essential to an explosion, however, that the oil should be initially in this state. Oil in the liquid phase will burn explosively under certain conditions, particularly if the oil is dispersed as mist. In an oil mist, vaporisation of oil will occur in the vicinity of the source of ignition, and may play a vital

* The lower limit of inflammability occurs when there is only just enough combustible present in the mixture to raise the temperature attained during combustion to a level at which flame is sustained; below this level of temperature the flame would not propagate. As air pressures are increased, and the thermal capacity of unit volume of air increases in proportion, correspondingly more combustible per unit volume (i.e., a proportionately higher partial pressure) must be supplied to prevent the mixture falling below the explosive limit.

part in the mechanism of combustion, but propagation of an explosion will not depend on the prior existence of an explosive concentration of combustible gas. Even solids such as coal dust will explode if finely dispersed and suitably ignited.

Oil mist can exist in high concentrations at low temperatures and a mist explosion is possible irrespective of the flash point of the oil. In other respects oil mists parallel oil vapour/air mixtures in the conditions required for ignition. There is evidence that at atmospheric pressure the lower limit of inflammability of an oil mist is identical with that of oil vapour in a similar system, and it is expectable that at higher pressures the lower limit of inflammability will remain about the same as in a vapour.

Oil mists can be formed by mechanical entrainment and dispersal of oil in moving air, and also as a result of vaporisation and subsequent condensation of oil. Condensed oil mists are of very small particle size, of the order of a few microns in diameter.

In order that a mist should form mechanically, air flow at a considerable speed is required, but — as already indicated — when the compressor is pumping air at a substantial rate the quantity of oil fed into or entrained in the air will fall far short of that necessary at the lower limit of inflammability. No great increase in the concentration of mist will take place on unloading the compressor. It would thus appear that any contribution by mechanically formed oil mist to an explosive mixture will always be very slight.

The development of a condensed oil mist in relatively high concentration also appears to be most unlikely. It is scarcely conceivable except, again, when air flow has ceased or fallen to a very low rate. Under such conditions, the source of oil vapour would again have to be deposits of oil on the surfaces of the system, and generation of vapour in substantial volume would again imply volatilisation of oil over sizeable areas at temperatures in excess of 450 to 500°F. It is very probable, however, that— as will be discussed later — an explosion or a fire could result immediately from the formation of large amounts of vapour at such abnormally hot areas.

A possibility exists that condensed oil mist may accumulate in volume through diffusion of vapour away from a localised source of vapour to closely adjacent cooler regions. A limited further rise in temperature in the area providing a source of vapour could then result in spontaneous ignition of an extensive inflammable mixture, resulting in an explosion which might be very violent. Nevertheless, although mist formation may perhaps in this way facilitate extension of an inflammable mixture it does not appear that it can increase the explosion hazard in systems under pressure, in which, as will be shown, spontaneous ignition may occur as soon as temperatures are high enough to develop an inflammable concentration of vapour.

deposits

Deposits soaked with oil must form reservoirs for the supply of oil vapour or oil mist, as described. In addition the possibility should be considered that thermal or oxidative decomposition of deposits might give rise to considerable volumes of inflammable gas.

Thermal decomposition (" cracking ") of the oil would not take place at a significant rate until temperatures far in excess of the flash point were reached. Oxidation can, however, take place at lower temperatures with the formation of gaseous products, principally carbon monoxide and carbon dioxide. Experiments carried out by the U.S. Bureau of Mines showed that carbon monoxide was evolved from typical compressor deposits when heated in air or nitrogen, and it was always accompanied by many times its own volume of carbon dioxide. The rate of evolution was very slow. Even at 200°C (392°F), which is about the flash point of a compressor oil, carbon monoxide was given off at the very low rate of less than $0{\cdot}2 \times 10^{-3}$ cu.ft./min. per lb. of deposit.

The lower limit of inflammability of carbon monoxide in air is 12·5%, and furthermore a mixture of carbon monoxide with more than 2·2 times its volume of carbon dioxide is non-inflammable in air in any concentration. It therefore seems unlikely in the extreme that evolution of carbon monoxide from deposits contributes significantly to the formation of an explosive medium. It may, of course, present a very serious atmospheric hazard in mines, but that is beyond the scope of this Paper.

We are therefore led, in the light of existing information, to the conclusion that oil vapour mixed with air is the most likely primary explosive medium. Deposits, however, should be avoided as far as possible, as they constitute a reservoir for oil and also may cause malfunctioning of valves.

SOURCES OF IGNITION

Perhaps the most mysterious element of a compressor explosion is the source of ignition. There is little factual information available on the subject and we are therefore obliged to consider what are the conditions necessary for the ignition of the explosive media described in the preceding section, and to compare these conditions with those existing in compressor discharge lines.

conditions necessary for ignition of oil vapour and oil mists

As has been stated, the ignition of an oil mist in air necessarily involves the prior vaporisation of some of the oil. However, in a fine mist the energy needed to vaporise oil locally is so small that initiation of combustion will occur in much the same conditions as ignition of oil vapour.

Mixtures of air and oil vapour or gaseous oil derivatives in the necessary proportions may be ignited by weak sources of energy such as a spark discharge of static electricity releasing energy of, say, 0·001 joule. (By contrast, the energy released on passage of the spark at the sparking plug of a gasoline engine is of the order of 0·1 joule.)

Particles of solid or liquid entrained in a moving

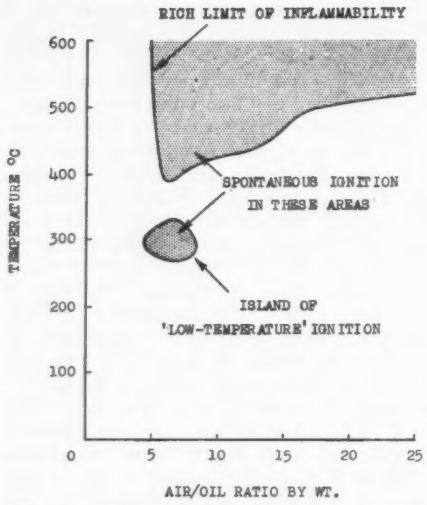

Fig. 1. Characteristic relationship between spontaneous ignition temperature and air/oil ratio at atmospheric pressure.

gas may acquire an electrostatic charge on coming into contact with boundary walls, for example, where the gas passes through an orifice. If the stream of particles should subsequently encounter an electrically insulated surface the charges may be conveyed to that surface, which may reach so high a potential as to discharge electricity as a spark. It is a matter of conjecture in what manner areas of the interior surfaces of the delivery system may become electrically insulated, but this possibility clearly cannot be disregarded and electrostatic discharge must therefore be recognised as a possible initiator of an explosion where an inflammable mixture is present. On the other hand the development of dangerously high electrical charges at such areas will be the more likely the higher the rate of gas flow, yet the accumulation of an inflammable mixture, as has been indicated, requires static conditions or very low rates of flow.

Mixtures of air and inflammable gas in explosive concentration at pressures considerably above atmospheric are also capable of igniting spontaneously at temperatures that can be regarded as relatively low, so low in fact that under the conditions necessary for oil vapour to reach dangerous concentrations its spontaneous ignition is probable.

The spontaneous ignition temperature of a mixture of oil vapour and air varies with both air/oil ratio and pressure. Recent work by Shell on oil mists, which can exist in inflammable concentration at room temperature, has shown in oils typical of air compressor lubricants a relationship between spontaneous ignition temperature and air/oil ratio with the general form represented in Fig. 1. The boundaries of the areas within which spontaneous ignition will occur vary in position with the conditions of the system, but a well-defined common factor is a considerable depression in the upper, continuous area at relatively low air/oil ratios, coupled with the existence of an isolated area, also at low compression ratios, where spontaneous ignition may occur at a relatively low temperature of around 270°C (518°F). The relationship between spontaneous ignition temperature and pressure at the lower limit of inflammability, or between spontaneous ignition temperature and air/oil ratio at high pressures, is not known with certainty. There is evidence, however, that at relatively low air/oil ratios, at which the lowest values of spontaneous ignition temperatures are obtained at atmospheric pressure, the relationship between spontaneous ignition temperature and pressure for a typical oil has the general form represented approximately by Fig. 2. The re-entrant shape of the curve at comparatively low pressures (the peninsula) reflects the existence of the island in

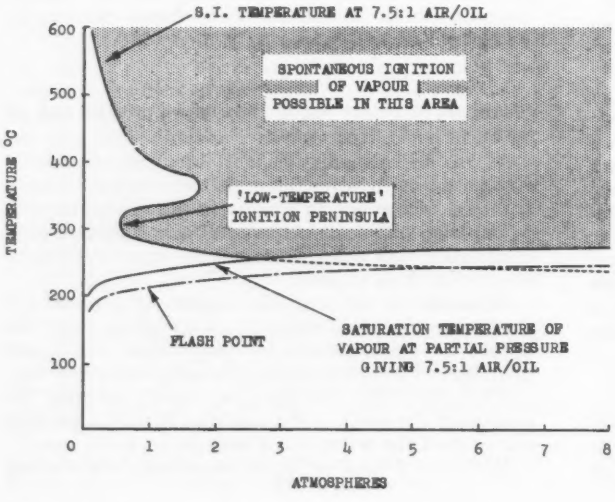

Fig. 2. Characteristic relationship between spontaneous ignition temperature and pressure.

Fig. 1. It is believed that the general trend at increased pressures is, as shown in Fig. 2, that the curve falls gradually from around 270°C at 1 atm, to say about 240°C (464°F) at 8 atm, and ultimately approaches asymptotically a value which may be in the region of 220°C (428°F).

If, as has been postulated for the generation of an explosive mixture, a considerable source of heat were to continue to operate when air flow had ceased or fallen to a very low rate, the partial pressure of oil vapour might reach its saturation value and the concentration of inflammable material in the vapour phase would thus depend on the prevailing temperature. An explosion would occur if the minimum temperature for spontaneous ignition at a given air/oil ratio at the prevailing pressure were below the temperature required to produce that air/oil ratio at the prevailing pressure. Above a certain range of pressure, therefore, an explosion will be possible at some temperature between the effective flash point of the oil and the temperature at which the saturation pressure of oil vapour provides the most easily ignitable mixture. The critical range of pressure is somewhat indeterminate, but in the case considered it may obviously be well below 7 or 8 atm. Curves showing the approximate saturation temperatures providing vapour concentrations both at the lower limit of inflammability and at 7·5 air/oil by weight are shown in the diagram for a typical compressor oil of closed flash point 415°F at atmospheric pressure. The viscosity of such a typical oil would normally be about 135 cs. at 100°F. It is possible that with oils heavier than those normally used spontaneous ignition will take place as soon as the flash point temperature is reached.

potential sources of overheating

discharge valves; leaks

It appears then that a metal, or metal oxide, surface at temperatures of the order of 240°F can be expected to ignite a mixture of lubricating oil and compressed air. The question arises as to whether such hot surfaces may be present, and if so in what circumstances.

It is well established that under adverse conditions discharge valves are capable of reaching temperatures of this order or more; in one case there is evidence that during operation the valves had reached temperatures of 280°C (536°F). Possible sources of such overheating have been discussed in a number of papers; a particularly useful study has been made by Vaughan, who carried out tests on valves in which leakage holes had been deliberately drilled. The matter is one for the designer; in this context it is, however, noteworthy that overheating of discharge valves could occur in some cases when the compressor is running unloaded.

A survey of reports of various compressor explosions has shown that in many of the incidents signs of overheating of discharge valves were found on subsequent investigation. It may be argued that the overheating was the result of the explosion rather than its cause, but it would perhaps be wiser at the present stage of our knowledge to assume that overheated discharge valves are a potential source of ignition.

A valuable study by the S.M.R.E. has drawn attention to the fire hazard associated with leakage through certain sealing materials at joints or patches. High-frequency vibration caused by escape of air generates frictional heat which is capable of starting a fire in the vicinity.

self-ignition of deposits

Another, and perhaps more widely quoted, potential source is the spontaneous heating to ignition of the deposits in the discharge system.

Spontaneous ignition of this kind takes place by the following process. Chemical reaction sets in between the deposit and the oxygen in the air. This reaction liberates heat which raises the temperature of the deposits, and consequently accelerates the rate of reaction, setting in train a process which, if not checked, leads to ignition. Checking of the process may occur by the loss of heat to the surroundings and to air passing through the deposit, in which case the temperature will rise to some finite value above that of the surroundings, but no further. Also, unless a supply of air is continually maintained the reaction rate may fall off through consumption of oxygen.

It may be seen, therefore, that the requirements for spontaneous ignition are (1) the attainment of an initial temperature high enough for an exothermic reaction to proceed at a significant rate, (2) good thermal insulation of the deposit, and (3) a supply of air to the deposit at a rate not too great to cool it, but sufficient to supply fresh oxygen for continued reaction.

The nature of compressor deposits is so variable that any consideration of circulation of air through them as they lie in the discharge system is bound to be very speculative. However, the deposits are certainly brought into close contact with air by a breathing process: as the pressure in the pipe line falls, air is sucked out of the deposits; and as it rises, air is driven in. Therefore the achievement of a suitable rate of ventilation is not unlikely. Considerable attention has been paid by various workers to these deposits and their oxidation. The U.S. Bureau of Mines in 1949 demonstrated the existence of a "carbon-oxygen complex" in certain compressor deposits taken from the discharge sides of air compressors following accidents due to explosions. They likened this substance to a similar substance produced during the spontaneous heating of coal, and suggested somewhat obliquely that it played a significant role in the initiation of compressor explosions. However, the complex decomposed endothermically in nitrogen, but exothermically in air, suggesting that continued oxidation was the heat-evolving process rather than decomposition of the complex itself.

Work was carried out by Cerchar on the oxidation in air at high temperature of fresh mineral oils dispersed on solid surfaces, which showed that with these imitation deposits oxidation set in at just as low a temperature as had been found by the U.S. Bureau

of Mines for their carbon-oxygen complex. It seems very likely that the oxidation of deposits is in fact essentially the oxidation of the oil with which the deposit is wetted. In the Cerchar work, experiments were carried out first with a rig blowing oxygen over various inflammable substances and later with a rig blowing air over imitation oil deposits and intended to parallel practical conditions. In the latter tests the air was at 7 atm pressure (gauge) and was blown at various speeds up to 5m./sec. through an oil-impregnated mass. The investigators treated as the critical factor the air temperature at which the temperature of the oil-impregnated mass began to exceed that of the air. This temperature was found to depend on the rate of the air flow. No increase in the temperature of the deposits was detectable at air speeds over 2m./sec. At low air speeds the critical temperature was well marked, and a number of values in the range 140 to 200°C (284 to 392°F) were obtained using oil-bearing deposits of various kinds at 12·5 cm./sec. These included one value of 154°C (309°F) with deposits taken from an air compressor.

Tests to establish temperatures of ignition of the gas produced by the oil-bearing mass showed that these are also affected by the flow of air. In these tests the deposits used consisted of rust or ferric hydrate impregnated with compressor oil. At low continuous air speeds (2 and 12·5 cm./sec.) ignition took place in oil/ferric hydrate with air temperatures in the range 170 to 200°C (338 to 392°F). When delivery was suddenly cut off ignition took place with both types of deposit at air temperatures in the range 200 to 240°C (392 to 464°F), in some cases where no ignition had taken place during air flow. In general, a sharp rise in the temperature of the deposits was observed on suddenly cutting off air flow, whether or not ignition occurred. The lowest ignition temperatures were obtained when delivery was resumed almost at once; under these conditions oil/rust ignited in one case at 207°C (405°F) and oil/ferric hydrate at 151 to 157°C (304 to 318°F).

An explanation of these results follows from the considerations discussed earlier. Dissipation of heat and availability of oxygen both increase with increase of air flow, but there is a certain slow rate of flow at which a progressive increase in the temperature of the deposits will begin at the lowest value of air temperature. The local concentration of inflammable vapour, of which a certain value is essential for ignition, will also depend on the rate of air flow, falling rapidly as this increases, and will only reach dangerous values when air flow is at a low rate or is temporarily interrupted. In relation to this, it is interesting to note that air compressor explosions have, in fact, occurred comparatively frequently when delivery has ceased or just after delivery has been resumed.

DETONATIONS

We have so far been discussing fires and explosions, mainly explosions. The serious accidents at coal mines in this country and France, which were referred to in the introduction, differed from more common explosions in that long air pipe lines from the receiver to the working face were ruptured in many places simultaneously. The large number of ruptures indicated to Charbonnages de France that a process akin to detonation had been taking place. This they confirmed by their extremely valuable investigation between 1949 and 1952, wherein they also showed that oil initially dispersed as a film on the surfaces of the pipe lines represented the bulk of the inflammable material participating in the detonation.

This work, which included experiments on a heroic scale using testpieces 250 mm. in diameter and up to 95 m. in length, demonstrated that lubricating oil initially in the liquid phase as a coating in a pipe line will explode if an effective source of ignition is present. In the Cerchar tests, the piping was charged with air at 7 kg./sq. cm. At this pressure a stoichiometric concentration of oil is provided in a 250 mm. pipe by approximately 30 grammes per metre, equivalent to a uniform film about 0·05 mm. thick. In some of the tests the oil was contained in troughs running the length of the pipe and in others it was spread over the inside surface, in both cases the deposits being of fresh oil. Violent explosions involving the propagation of pressure waves at speeds of about 1,200 m./sec. were produced with oil concentrations of 60 and 180 g./m.

It is clear from the Cerchar work that to initiate detonation of an oil film in a pipe requires a very powerful source of energy, equal to that provided by prior explosion of a gaseous inflammable mixture in considerable volume. There is little doubt that only such a primary deflagration would suffice. Cerchar used mixtures of methane and air in an attempt to produce these detonations and found it necessary to enrich the gas mixture with oxygen. A similar increase in the effectiveness of the gas mixture might have been obtained by using a larger charge.

The manner in which oil, initially resting on the walls of the piping, becomes sufficiently well dispersed in the compressed air to support a detonation wave is not immediately clear. M. Loisin, of Cerchar, has suggested that adiabatic compression of the air in a pressure wave raises the temperature sufficiently to distil the film of oil from the pipe. However, Dr. Tideswell, of S.M.R.E., considered this explanation inherently improbable because the transference of heat from the compressed gases to the oil film would be not nearly rapid enough. He suggests that the blast in front of the flame (the violent movement of air travelling down the pipe ahead of the flame), assisted by the violent vibration induced in the pipe, tears the film of oil from the walls of the pipe to make an oil suspension, near the wall, which is capable of propagating flame. Recent work on high speed aerodynamics has shown there is intense turbulence where shock waves in gases interact with boundary layers close to walls, and this would seem to substantiate Tideswell's explanation.

The sequence of events leading to a detonation in a long pipe would thus be: (1) the accumulation of an explosive medium in the discharge line near the compressor, and in the receiver; (2) the ignition of this medium, giving a primary explosion near the

compressor (up to this stage we have a normal explosion); (3) the propagation of shock waves down the long pipe line from the receiver; and (4) the transformation of one of these shock waves into a detonation wave.

The occurrence of a detonation or of a normal explosion in a compressed air system thus depends upon whether stages 3 and 4 follow upon stages 1 and 2.

Since the amount of oil required for a detonation wave as described by Cerchar represents only a very thin deposit, it is practically impossible to avoid its presence in the discharge system by preventing carry-over of oil from the compressor. In the avoidance of a catastrophic detonation, therefore, the critical factor is prevention of the primary explosion of an extensive accumulation of inflammable gas.

operating temperatures; safety precautions

An obvious direction in which a reduction in the fire and explosion hazard may be sought is the use of lubricants with greater resistance to fire than that of mineral oils. Studies are being made of possibly suitable fire-resistant materials, but it is evident that special care is likely to be required with such materials in this application — for example, because of possible toxic hazard. Moreover their cost is likely to be several times that of mineral oils, and this may also limit their applicability. However, providing reasonable precautions are taken, on the following lines, mineral oils are entirely capable of safe operation in compressed air systems.

Abnormally high operating temperatures, no matter how they arise, will increase vaporisation of oil, and under certain conditions of air flow may permit the concentration of oil in the vapour phase to reach the lower limit of inflammability. In this respect a maximum discharge temperature is prescribed by the flash point of the oil under operating conditions. A figure of 50°F above the flash point in a standard test has been suggested.

It is possible that the laboratory tests that have been carried out with oil deposits to establish conditions for self-ignition have imposed more severe conditions than occur in practice. If any differences in this respect are ignored, the experimental work would indicate that for complete security discharge temperatures should not exceed 150°C (302°F) or perhaps slightly less. Apart from an element of doubt as to the immediate relevance of the experimental results to practical operation, considerable variation will exist between one installation and another in the degree in which factors other than temperature favour an explosion. Under the most unfavourable conditions the maximum safe working temperature may be around 150°C, but in other cases it will be higher. Very many compressors do in fact operate satisfactorily with discharge temperatures over 150°C. It is to be expected, however, that increase of temperature over 150°C will be accompanied by a rapid rise in reaction rates, and there will be a much greater likelihood of potentially dangerous conditions at temperatures of the order of 200°C (392°F). Such conditions will almost certainly exist at 250°C (482°F).

It is to be expected that the generation of large volumes of oil vapour, or the development of exothermic reactions involving the liberation of considerable volumes of gaseous reaction products, would require exposure of oil to high temperatures for a measurable length of time and in sizeable quantities. This would imply that stagnant or slow-moving oil would have to be present in quantity at places at high temperature, particularly near the discharge valves. To avoid this the designer and operator should take every precaution to minimise deposit formation.

Design points are that the oil should not be able to remain in pockets in areas of high temperature, and that all parts of the system, especially those near the discharge valves, should be accessible for cleaning. Consideration might also be given to the desirability of using rust-resisting materials or coatings, with superior finish, on the nearer elements of the discharge system — for example, the pipe to the after cooler— to prevent aggregation of deposits based on oil-soaked rust.

Operating points are that the rate of oil feed should be the minimum consistent with effective lubrication; the inlet air should be efficiently filtered to reduce the quantity of solid matter capable of agglomeration with oil; at intervals the system should be inspected and cleaned as necessary.

"INDUSTRIAL USES OF ROTARY COMPRESSORS" — see pages 490 - 499

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Industrial Uses of Rotary Compressors

by JAMES HODGE, M.A., M.I.Mech.E., A.F.R.Ae.S., M.A.S.M.E.

A Paper presented at the Compressed Air Conference, Cornwall, in April, 1958

IN the past, the supply of compressed air at pressures upwards of 50 lb./sq. in., for industrial use, has been achieved mainly by means of reciprocating compressors. Recently, however, there has been a growing tendency to use rotary compressors of various kinds. It is of interest to examine the advantages likely to be gained by the change and the merits of the different types of rotary compressor which are available.

The main sub-division for all types, whether rotary or not, is between positive displacement and aerodynamic compressors. The former, which includes the reciprocating type, comprises all those compressors in which the gas to be compressed is admitted to a space, which is then closed. The volume of the space is next reduced by mechanical means and so the gas is compressed before being discharged at the delivery pressure. Compressors of this kind are distinguished by several features which are important to the user. Of these, the most important are:

1. The throughput of a given compressor in terms of volume flow (F.A.D.) is dependent almost entirely on the speed of the machine, and is almost directly proportional to it.

2. The machine is designed for a particular pressure ratio and this cannot easily be altered in a given case (except by such complex expedients as a variable compression ratio reciprocating machine). The result is that optimum efficiency is obtained in the region of operation near the " built in " pressure ratio and any large departures from this result in a loss of efficiency.

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After a short period in the gas turbine department of The English Electric Company, he spent nearly two years at A.E.R.E., Harwell, on reactor design work. He then joined the newly-formed consultancy department of Power Jets (Research and Development) Ltd., where he is now Chief Engineer.

For two periods in 1953 *and* 1954, *Mr. Hodge was visiting Professor of Mechanical Engineering at Columbia University, New York.*

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3. Perhaps the most important advantage of the positive displacement type is that it is entirely free from the form of flow instability known as " surging ", which is one of the difficulties associated with the aerodynamic type and which will be described more fully later.

A characteristic typical of those obtained from positive displacement machines is shown in Fig. 1.

Aerodynamic compressors, on the other hand, work on entirely different principles and have different operating characteristics. Basically, the mode of operation is to convert velocity head into static pressure by aerodynamic means. This can be done in either rotating or stationary parts and entails first of all the creation of a relative velocity by the rotation of a bladed wheel of some kind. Usually this relative velocity is converted to static pressure, partly in the rotating wheel itself and partly in a subsequent stator. Fundamentally, the conversion requires flow through a passage which is diverging in the direction of flow (provided that the relative velocity is subsonic). The forces which are effective are those of aerodynamic "lift" and derive fundamentally from circulation round the blades or vanes, moving or stationary.

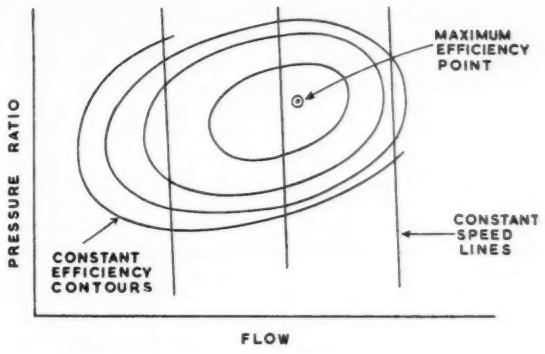
In any aerodynamic compressor, the total torque required equals the sum of the changes of angular momentum of the air which take place in all the rotor elements — there may, of course, be one rotor stage or many. The work done on unit mass of fluid is proportional to the sum, for all the rotor stages, of the changes, through each rotor stage, in the product of blade speed and whirl velocity of the fluid. For large pressure ratios, therefore, either high blade speeds or a number of stages are required. The limitations on the operation of aerodynamic compressors are as follows:

1. The maximum pressure ratio obtainable from a given compressor is limited partly by mechanical considerations of running at high speed, and partly by aerodynamic factors, chief of which are the Mach numbers within the compressor. Generally, though there are exceptions, the attainment of local sonic velocities causes a loss of efficiency and prevents further increase of pressure ratio.

2. The efficiency can be maintained at a high value over a wide range of pressure ratios, though at any given pressure ratio the flow range within which it can be maintained is limited, irrespective of any change of speed.

3. The pressure ratio obtained is mainly dependent on speed (for a given inlet temperature). Mass flow rate has some influence on pressure ratio, at a given speed, but usually this is small within the high efficiency zone.

4. At a given speed, the flow is limited, at the lower end of its range, by "surging". This is a form of flow instability closely analogous to stalling of an aeroplane wing and is basically the result of overloading some component, in the aerodynamic sense. Normally, it is considered to be impossible to run in the surge region as the flow is fluctuating so violently and is even liable to damage the machine if allowed to persist for very long. At the other end of the flow range, the limit is set by "choking"; that is, the Mach number in some part of the machine reaches unity and any further increase of flow, under the prevailing conditions of temperature and pressure, is impossible. Especially at high pressure ratios the two limits, surging and choking, may very nearly coincide, so that the throughput is dependent only on speed, as in the case of the positive displacement machine. A typical characteristic for an aerodynamic machine is shown in Fig. 2.

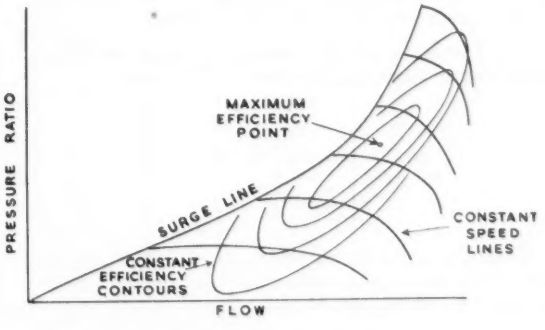


TYPICAL FORM OF CHARACTERISTIC OF A POSITIVE DISPLACEMENT COMPRESSOR

Fig. 1.

features of importance in a compressor

So far only the distinctions between the two main types of compressor have been considered. The kinds of machine included in each class or their advantages and disadvantages have not been described. The features which are likely to be important in a compressor will now be discussed; naturally the degree of importance of the various factors changes with the duty and the output required and so on.



TYPICAL FORM OF CHARACTERISTIC OF AN AERODYNAMIC COMPRESSOR

Fig. 2.

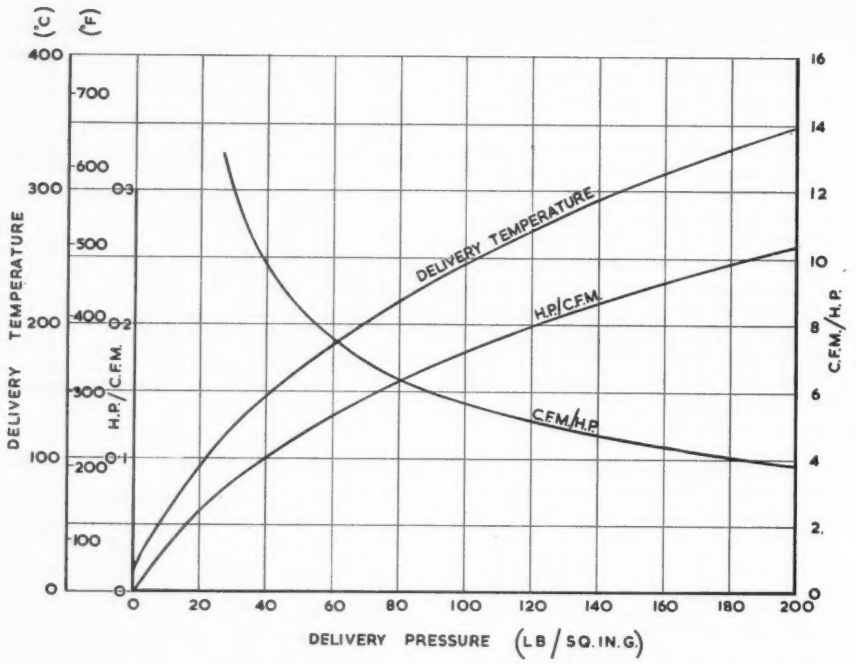


Fig. 3. Power required and delivery temperature for isentropic compression from inlet conditions 14.7 lb./sq. in. abs. and 15°C (59°F).

efficiency

The efficiency is, of course, a measure of the power input required compared with that required by an ideal process. In the case of gas compression, either of two different ideals can be used as the basis for comparison. These are the isentropic and isothermal processes.

In the isentropic (often, but inadequately, called adiabatic) process, the compression follows the law $pV^{\gamma} = \text{constant}$, there are no heat losses to (or gains from) the surroundings, and the process is reversible, that is, there are no friction or turbulence losses which would cause an increase of entropy. This is the best possible process in the absence of cooling.

For 1 cubic foot per minute at inlet, isentropic compression work is given by:

$$\frac{\gamma}{\gamma-1} p_1 \left\{ \left(\frac{p_2}{p_1} \right)^{\frac{\gamma}{\gamma-1}} - 1 \right\}$$

Taking $\gamma = 1{\cdot}4$ for air and p_1 as 14·7 lb./sq. in. abs. the power required for isentropic compression to any pressure p_2 (lb./sq. in. abs.) is:

$$\frac{3{\cdot}5 \times 14{\cdot}7 \times 144}{33{,}000} \left\{ \left(\frac{p_2}{14{\cdot}7} \right)^{0{\cdot}286} - 1 \right\} \text{h.p./c.f.m.}$$

$$= 0{\cdot}2245 \left\{ \left(\frac{p_2}{14{\cdot}7} \right)^{0{\cdot}286} - 1 \right\} \text{h.p./c.f.m.}$$

Fig. 3 shows this equation plotted against delivery pressure up to 200 lb./sq. in. abs., both as h.p./c.f.m. and its inverse, c.f.m./h.p. Also shown is the delivery temperature which would be obtained, assuming an inlet temperature of 15°C (59°F). This is obtained from the expression:

$$T_2 = T_1 \left(\frac{p_2}{p_1} \right)^{\frac{\gamma-1}{\gamma}}$$, where the temperatures are absolute values.

In the isothermal process, heat is extracted from the gas continuously during compression so that its temperature remains constant. Apart from this there are no friction or turbulence losses. Isothermal compression is the best that is conceivable (provided that no heat sink with a temperature lower than that of the entering gas is available) and absorbs the minimum possible amount of power.

For 1 c.f.m. at inlet, isothermal compression work is given by:

$$p_1 \log_e \left(\frac{p_2}{p_1} \right)$$

Again taking $p_1 = 14{\cdot}7$ lb./sq. in. abs. gives:

$$\frac{14{\cdot}7 \times 144}{33{,}000} \log_e \left\{ \frac{p_2}{14{\cdot}7} \right\} \text{h.p./c.f.m.}$$

$$= 0{\cdot}06414 \log_e \left\{ \frac{p_2}{14{\cdot}7} \right\} \text{h.p./c.f.m.}$$

Fig. 4 shows this equation plotted against delivery pressure, also up to 200 lb./in.^{2} abs., both as h.p./c.f.m. and c.f.m./h.p. In this case, delivery temperature is, of course, constant at the inlet value, for all pressures.

It is common practice with smaller industrial compressors to express the performance in terms of c.f.m./h.p. rather than as an efficiency. This is very convenient as it enables the power required to be calculated immediately. On the other hand, it does not give any idea of how good or bad the compressor is in absolute terms, compared to what is ideally possible. In this connection, useful figures to remember (taken from Figs. 3 and 4) are that for compression to 100 lb./sq. in. g from 14·7 lb./sq. in. abs. the isothermal process gives a value of 7·6 c.f.m./h.p. and the isentropic 5·6 c.f.m./h.p. So a compressor with a power requirement of, say, 4 c.f.m./h.p. would have an isentropic efficiency of 71·5% and an isothermal efficiency of 52·7%.

Taking a broader view of the production of compressed air, the compressor efficiency is not the only, or necessarily the most important, factor in running cost. It is the combination of compressor and driving agent which together define the overall efficiency. Since a variety of means can be used to drive a compressor (electric motor, petrol or diesel engine and gas turbine are the most likely) the only ultimate comparison, to allow for the different fuels (including electricity) is on a basis of fuel cost per unit of air produced; that is, in British units, some unit such as pence/1,000 cu. ft. (at the specified pressure). However, where units are to be compared which use the same kind of fuel a convenient basis is pounds of fuel per hour/c.f.m.

size and weight

These two factors are, of course, most important for portable plant. They are often, though not always, fairly closely related — the smallest machine may not always be the lightest one. Both size and weight are, however, linked to speed of the compressor as well as to the type. For any given type (and even for different types in many cases) the faster the compressor runs the lower will be its specific volume (cu. ft./c.f.m.) and specific weight (lb./c.f.m.). Again the size and weight of the complete outfit — compressor and power source — are the really significant

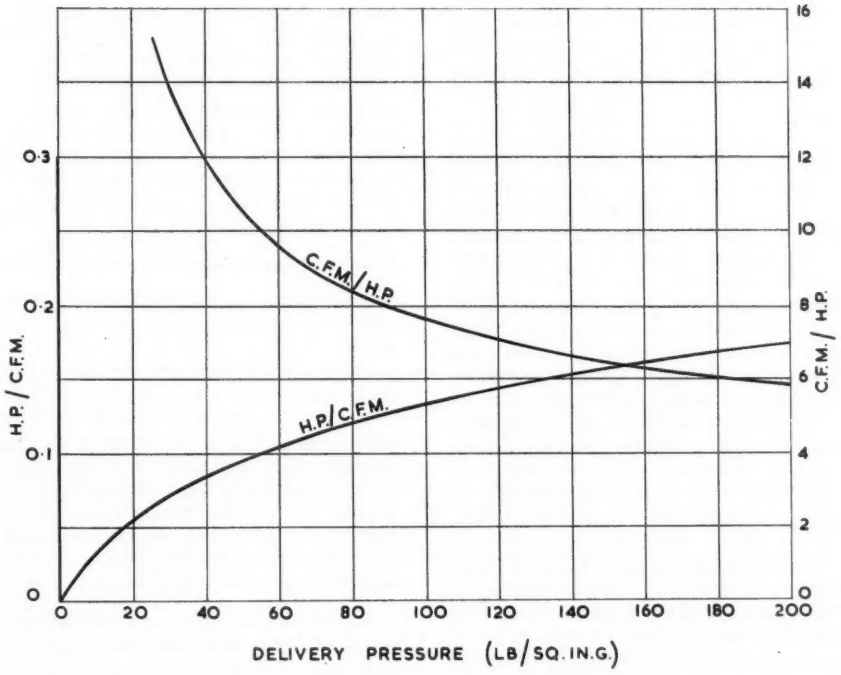


Fig. 4. Power required for isothermal compression from inlet pressure of 14.7 lb./sq. in. abs.

factors. There is little point in developing a very light, compact, high-speed compressor if it is to be driven by a very heavy, low speed engine needing also a step-up gearbox. For example, if the compressor and engine are of equal weights, the limit to weight reduction, if the same engine is used, is 50%, even if the weight of the compressor is reduced to zero. In comparing weights and sizes one has to be careful that the comparison is a fair one and that the same gear, in so far as it is necessary in each case, is included in all cases. This applies particularly to receivers, chassis, wheels, fuel tanks, oil in the system for compressor cooling and other items which could be omitted to produce a favourable figure.

initial cost

There is little to be said about this aspect in a general way, except that usually high efficiency and high cost go together to a large extent. For example, a diesel engine drive is more expensive than a petrol engine. In considering cost, all the necessary ancillaries must be included, of course, such as receivers, air cleaners and so forth, as well as the driving engine.

control

One of the more difficult problems, particularly with aerodynamic compressors, is to be able to supply a variable demand, from zero to full output, at as nearly as possible constant delivery pressure. With a positive displacement compressor, this is usually done either by varying the speed of the compressor to suit the output, or by " unloading ", or blowing off. If the speed is varied, of course, there is a time lag and also the range of output which can be covered by this means is limited by the characteristics of the engine. Outside this range, and in order to get a more rapid response, unloading or blow-off are necessary. The receiver is necessary particularly on positive displacement machines for two main reasons. One is that it permits, by means of its capacity effect, some mismatching between the instantaneous demand and the instantaneous delivery from the compressor. This means that the control system, whatever it is, has time to operate and bring the two into step before any very big change of pressure occurs. The control system can be given a range of pressures within which it does not react, so that it is not continuously in operation, probably causing hunting of the whole system. With some kinds of compressor, the pressure-volume characteristic is very steep indeed and a sudden reduction of output could, if there were no capacity, result in a dangerous rise in delivery pressure — too rapid for the control system to cope with.

With some oil-flooded compressors (such as the vane types) the receiver also contains the means for recovering the oil, generally in the form of some kind of wool-packed filter assembly.

Where the pressure-volume characteristic is comparatively flat, as in the case of aerodynamic compressors, and in any case the maximum delivery pressure at a given rotational speed is limited by surging, there is usually no need to use a receiver and some direct method of avoiding surging must be used. In any case, aerodynamic compressors are likely to be used only when large flows are required, so that the time lag to be gained by any reasonable sized receiver would be too small to be worth while.

Apart from the need for the control system to prevent dangerous conditions such as excessive pressures or surging, it should also enable the whole system to operate at the highest possible efficiency over the whole load range. That is, the c.f.m./h.p. (or cubic ft. per lb. of fuel) should be kept as near the maximum value as possible. For this reason, blow-off of surplus air, the simplest form of regulation, is undesirable except as a last resort.

noise

The amount of attention which is paid to the noise aspect is somewhat dependent on the use of the machine — its location and the type of equipment it supplies. For example, there is little incentive to make a quiet compressor set if it is to be used to drive road breakers which are themselves very noisy. Apart from the noise produced by the driving engine, the compressor generally produces noise in three ways — from its inlet, its delivery and internal mechanical noise, from gears or valves. Rotary compressors produce sounds of different kinds from the reciprocators and varying greatly from the low speed types to the high speed aerodynamic ones. Details of the design of the latter can affect their acoustic characteristics greatly, but they tend to have a high-pitched whistle, emanating from the intake, which can be very irritating. However, this can usually be much reduced by a fairly simple form of silencer, combined with an air cleaner. It is probably true to say that compressor noise in general could be reduced, but this has not usually been done because it is not very important compared with the noise from the air using devices and the driving engine.

cleanliness and temperature of air delivered

A particular virtue of the aerodynamic compressor is that it should not, and normally does not, cause any contamination of the air with water or oil. It is important from the point of view of the aerodynamic performance that no oil should be allowed to enter the airstream, and a good deal of trouble is taken to ensure that oil from bearings at the inlet end of the machine does not escape. Of the other types, the oil flooded machines with oil separator after the compressor are in many cases remarkably good in this respect and very little oil indeed leaves the machine with the air. A small quantity of oil is not by any means always harmful, of course.

Air delivery temperature is important mainly in its effect on equipment and personnel using the air. In particular, too high temperatures are not permissible where rubber hoses are used and most air-using machines are designed with this limitation in mind.

Since even isentropic compression to a delivery pressure of 100 lb./sq. in. g (from inlet conditions of 15°C and 14·7 lb./sq. in. abs.) involves a temperature rise of about 230°C (414°F), it is obvious that with all compressors some cooling is necessary so long as those limitations exist. If the limitations could be raised, then more output could be obtained from the same mass of air, so it should always be borne in mind that the need for cool air is an arbitrary requirement imposed by external factors.

If the cooling contributes towards reducing the compression work required to reach a given pressure, then it is desirable. If it takes place after compression and has no effect on the power requirement, it is fundamentally undesirable and is only done as a matter of convenience.

Cooling within the compressor, as a means of approaching isothermal compression, is achieved most effectively in the oil–flooded rotary compressors. The intimate contact of the cooling oil (which also serves for lubrication and sealing) maintains the air temperature at a low value throughout. With this kind of cooling, however, no half measures are possible — if insufficient oil is used, what there is will be damaged by heat and also will be ineffective for its other duties such as lubrication and sealing. Other means of cooling are by intercooling between stages and water-cooled compressor casings. At best, the former can give, in a single cooling stage, an improvement equivalent to going half way from isentropic to isothermal compression.

reliability and ease of maintenance

These are factors which are of the utmost importance either in a works where many services and machines may depend on the supply of compressed air, or on outside work where also repairs and maintenance are difficult to carry out. Generally reliability should be improved by the change from reciprocating to rotary motion, especially in cases where rubbing contact can be avoided. High rotational speeds are not in themselves liable to cause any trouble, provided the bearing designs are good and proper precautions are taken with regard to balancing. The transition to higher speed machines helps maintenance in so far as ease of handling is concerned, but often means more delicate parts.

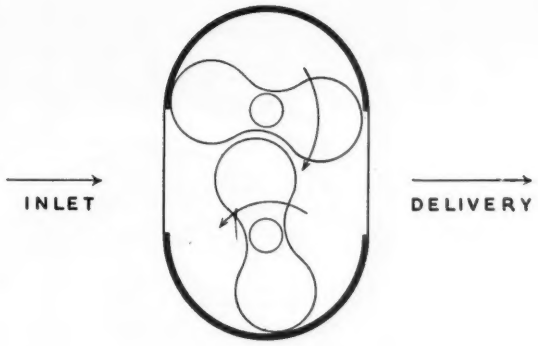
types of compressor:

1. Positive displacement

The main types of rotary positive displacement compressors which have been developed to varying degrees, for a wide variety of purposes, are as follows:

the Roots blower;
the BICERA supercharger;
the Lysholm compressor;
the vane type compressor.

There are many minor variants of these, and other types have been proposed, but none are known to be in widespread use. The attributes of each will now be described briefly, with particular reference to the features of importance which were discussed above.



TYPICAL ROOTS BLOWER

Fig. 5.

the Roots blower

This is probably the oldest established rotary positive displacement machine. Its construction is shown in Fig. 5. There is in fact no volume change of the displaced fluid due to the geometry of the rotor and stator parts, and compression is due entirely to back-flow from the delivery side as the displacement volume is brought into connection with it. Because this is not inherently an efficient process and because of the great difficulty in reducing leakages, the pressure rise in a single stage is small, seldom exceeding 8 to 10 lb./sq. in., and efficiencies are low. These blowers are made in a very wide range of sizes for duties ranging from engine supercharging to steel-works cupola blowing. Speeds are comparatively low, suitable for direct drive from an engine or motor. They can be cheap and robust, not very light in weight and do not contaminate the gas with oil as there is no lubricant in the rotor space and no rubbing parts. They can accommodate dirty gas if necessary, as they have no very fine clearances. A variant on the simple two-lobed Roots blower is a three-lobed version. This gives somewhat smaller leakage and can be used for slightly higher pressures, but is still more a " blower " than a compressor.

the BICERA supercharger

This is a newcomer to the rotary compressor family and is not yet in use to any extent. However, it is interesting as one approach to the design of a reasonably simple and cheap machine for fairly small flows and pressure rises. It is suitable for rather higher pressure ratios than the Roots blower and gives a considerably better efficiency. Figs. 6 and 7 show the construction of the compressor and its mode of

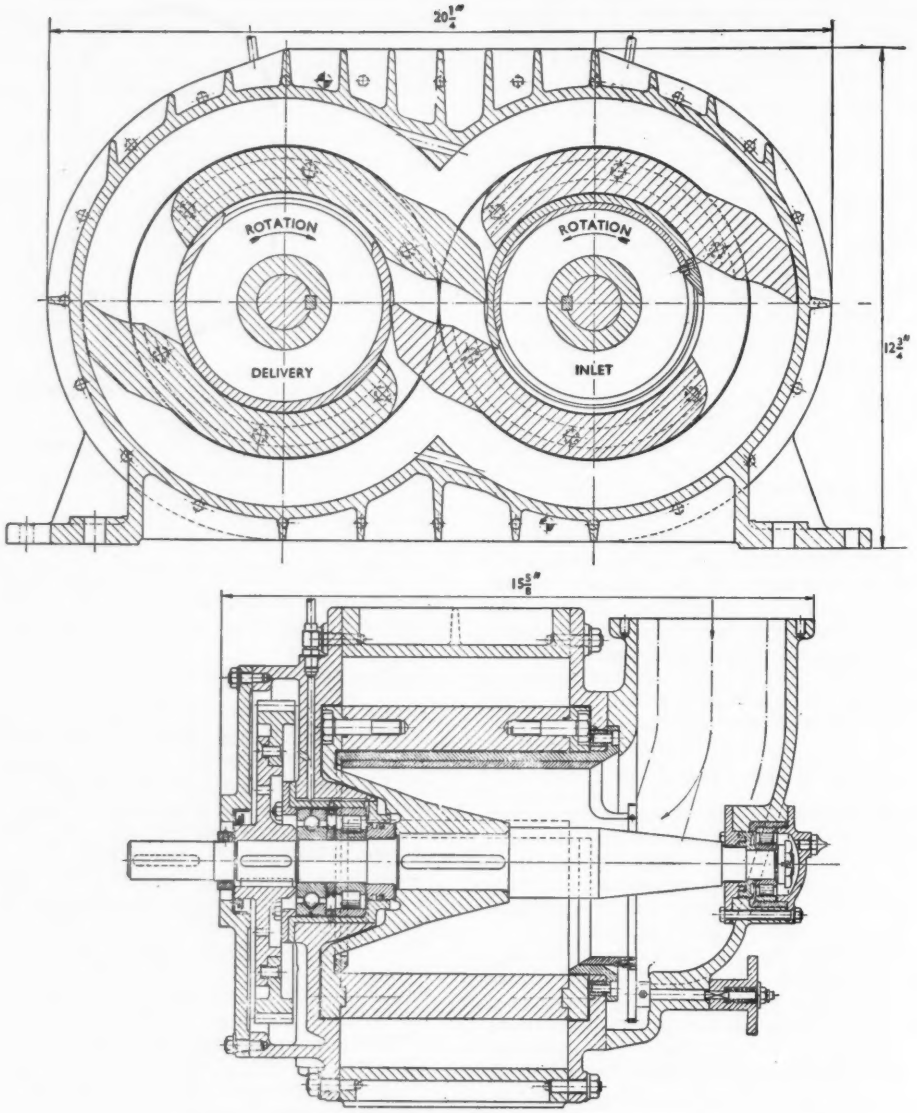


Fig. 6. Assembly drawing of Bicera No. 2 compressor.
(Courtesy of The Institution of Mechanical Engineers.)

operation. These are reproduced from Ref. 1 which gives a much more detailed description and performance figures. Its main advantages over the Roots blower are that it achieves the greater part of its compression effect directly by an internal volumetric change during rotation, and that it does not suffer nearly so much from the effects of leakage. It has apparently been tested up to a delivery pressure of about 20 lb./sq. in. g. and peak isentropic efficiencies are in the range of 65 to 75%. The example shown has a volume of about 2·4 cubic ft., weighs 189 lb. and has a capacity of roughly 700 c.f.m. at 3,500 r.p.m. As in the case of the Roots blower, it needs no internal lubrication so does not contaminate the air delivered. It is possible that it could be designed for higher pressure ratios with reasonable efficiency, but it seems unlikely to be capable of much improvement in this respect. Multi-staging with intercooling would be possible. An interesting feature is that, by controlling the inlet valve timing, the delivery pressure and throughput can be varied conveniently, which could be a useful feature in some applications.

the vane type

This is another old-established type of compressor, but it has become much more prominent in the past few years because of the introduction of the oil flooded version. The principle of operation is shown in Fig. 8, from which it can be seen that the rotor which has a number of radial, axially extending slots, is mounted eccentrically in the casing. In the slots are vanes which slide in and out as the rotor revolves, thus changing the volume of the spaces enclosed between adjacent vanes. This type can be designed for comparatively high pressure ratios and is used to produce 100 lb./sq. in. in two stages.

All the desired compression is achieved by direct internal volume change and leakage losses are much reduced because there are a number of vanes forming seals between the high and low pressure zones. Again this type is comparatively straightforward to manufacture, and is in fact made for a large range of sizes and pressures, from tens to several thousands of cubic feet per minute and for vacuum pumps as well as delivery of air at up to 250 lb./sq. in. In both the "dry" and "flooded" versions, two stages are generally used to achieve 100 lb./sq. in. g, the former having water-cooled casings. Efficiencies are obtained corresponding to deliveries of up to about 5 c.f.m./h.p. in the large, slow running machines. The oil-cooled version is used in the smaller portable machines and gives a figure in the region of 3·5 c.f.m./h.p. at 100 lb./sq. in. g. This operates at a higher speed, so being more compact and lighter in weight. In one well-known manufacturer's range, weights, including engines and all accessories, range from about 30 lb./c.f.m. down to 17 lb./c.f.m. as the output increases from 120 to 600 c.f.m. This is not a very marked reduction over some of the reciprocating types and serves to emphasise the point made earlier about the importance of the weight of the driving engine and other equipment.

the spiral lobe type

This type of compressor was first proposed by Lysholm in Sweden and is now known variously by his name or as the S.R.M. or Howden compressor. It consists of two lobed rotors, meshing together but geared so that they do not actually touch. The lobes are helical in form and the flow of air is in a direction generally parallel to the rotor axes. The rotors run in a figure-of-eight shaped casing. Again in this case the whole of the compression can be accomplished in the rotors. Pressure ratio in a single stage is limited by considerations of leakage, rotor stiffness, deflection and expansions. Maximum single stage pressure ratios available at present are up to 5 : 1, with throughputs ranging up to about 10,000 c.f.m. In two-stage stationary applications, compressing to 100 lb./sq. in. g. the isothermal efficiency is about 66% (5 c.f.m./h.p.). Since speeds are comparatively high (over 10,000 r.p.m. in small sizes) this is a compact compressor and is sometimes used for aircraft work, such as cabin pressurisation. It used to have the reputation of being exceedingly noisy, but this difficulty has now been largely overcome. There are

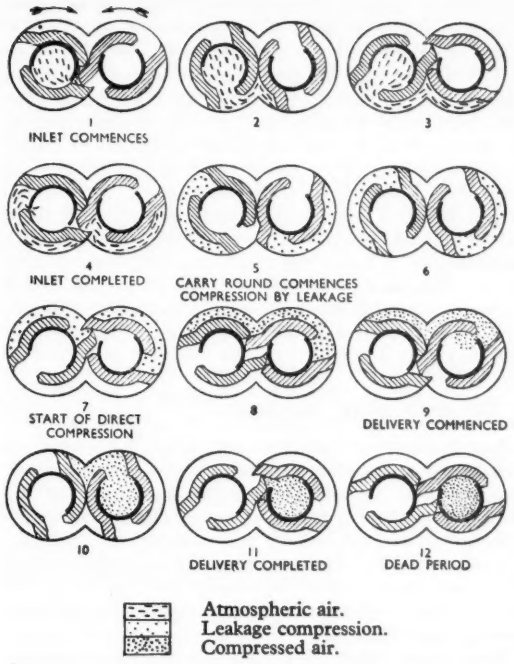
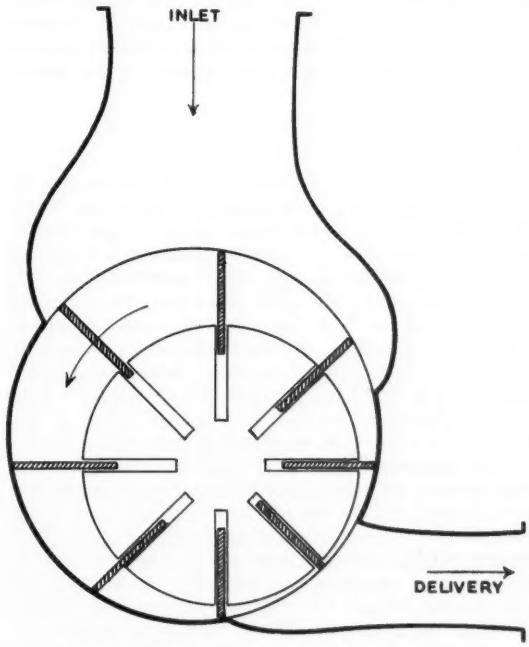


Fig. 7. Diagrammatic path of a single air charge through two-lobe compressor.
(Courtesy of The Institution of Mechanical Engineers.)



VANE TYPE COMPRESSOR

Fig. 8.

no rubbing parts and no internal lubrication is required so that the air is delivered free of oil. Water-cooled casings and oil-cooled rotors are often employed where the higher pressure ratios result in appreciable temperature rises. Manufacture is considerably more difficult than in any of the types so far discussed, as the helical-lobed rotors are complex shapes which must be made with a high degree of accuracy. Recently special purpose machines have been developed which should help greatly with these production problems. Given sufficiently accurate manufacture, it seems that this is the most elegant and efficient solution of the rotary positive displacement compressor problem which has so far been evolved, but it has yet to achieve very widespread use and popularity.

2. The aerodynamic compressors

Aerodynamic compressors are of two main types — centrifugal and axial. Sometimes the two types are combined. In principle, both are similar in that the work input to the rotor causes a change in whirl velocity of the air, which is converted to pressure. The main difference is that the centrifugal makes direct use of the centrifugal force field produced by the rotation to help the energy conversion process, but the axial does not.

Both types have been developed to the greatest extent in connection with aero-engine gas turbines where light weight, small size and high efficiency are of the utmost importance. Although they were known from before the beginning of this century, it is only the advent of the gas turbine in one form or another which has led to such advanced performance as is now possible. First came the supercharger for reciprocating aero-engines which was often a centrifugal and then the gas turbine as a prime mover, using either type.

the centrifugal compressor

The centrifugal (a typical one is shown in Fig. 9) is usually considered to be capable of a pressure ratio of about 4:1 in a single stage (using air at normal ambient temperature). This necessitates a rotor tip speed of about 1,500 ft./sec., which obviously involves high stresses. Isentropic efficiencies in the region of 80% are achieved at this pressure ratio, rising to something like 85% at lower pressures. Recently, there have been strong rumours from the United States that pressure ratios of 7 or 8 have been attained in a single stage, with efficiencies of about 75%. This implies rotor tip speeds of at least 1,900 ft./sec. and the stresses must be near the limit for materials with present day strength/weight ratios. Also serious aerodynamic difficulties in the design of the diffuser system must have been overcome. It is usual to employ much lower stage pressure ratios (1·5 to 3·5) in industrial applications in order to keep down stresses and obtain the highest possible efficiencies. Intercooling is comparatively easy with multi-stage centrifugals, as the air is delivered to the outside diameter after each stage, where it can be cooled before being led into the next stage.

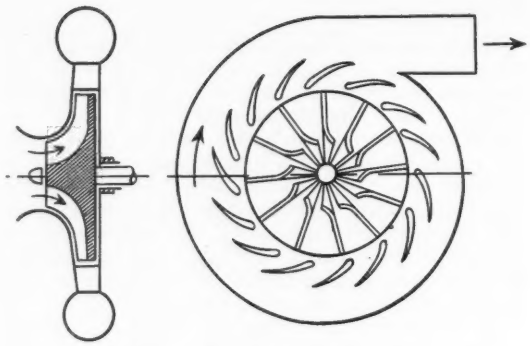


Fig. 9. Centrifugal compressor.

It is not usually considered worth while using a centrifugal for flow quantities below about 500 c.f.m. and much larger volumes are preferable, as otherwise sizes are tiny and rotational speeds very high, sometimes up to 50,000 rp.m. or even higher. The upper limits on throughput with aerodynamic compressors are purely those of manufacturing capacity and the supply of power to drive them.

The detailed shape of the characteristics of centrifugals can be varied widely. For example, a vaneless diffuser system gives very wide operating range between surging and choking and in some cases may almost eliminate surging. However, this is only possible with low stage pressure ratios and entails rather low efficiencies. Vaned diffusers can give much higher efficiency and stage pressure ratio, but sacrifice width of characteristic. Swept-back impeller vanes achieve something of the same object, but again can only be used at low pressure ratios. To give some idea of size and speed, a typical single sided centrifugal with a 20-in. diameter impeller (about 3 ft. 6 in. overall diameter of compressor) running at 17,000 r.p.m. would give a delivery pressure of about 45 lb./sq. in. g. with a throughput of about 15,000 c.f.m. The volume flow could be reduced considerably without having to increase the

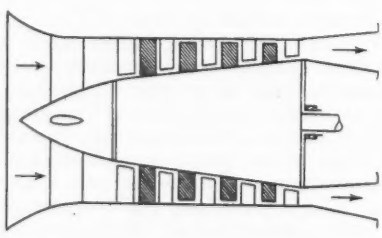


Fig. 10. Axial flow compressor.

speed or decrease the size, perhaps down to about 5,000 c.f.m. Weight can be very low — for a two-stage machine to deliver air at 100 lb./sq. in. g., a figure of 10 to 20 c.f.m./lb. for the compressor alone should be quite possible. Most industrial machines would use several stages for 100 lb./sq. in. g. air and would be very much heavier and bulkier.

Manufacture of centrifugals requires good accuracy, sound forgings for the impellers and a technique for making the curved inlet guide vanes. No very special techniques or machines are needed and cost per c.f.m. is not likely to be high especially with the larger flows.

the axial compressor

Serious development of the axial flow compressor began only in the 1930s. A typical modern machine is shown in Fig. 10. Previously, only low pressure ratio fans and a few very inefficient multi-stage machines had been built. The great development incentives for aero-engine gas turbines have been the very low frontal area and the potential high efficiency. Also high pressure ratios up to about 8 (needing not less than eight or nine stages) are attainable on a single shaft without intercooling, whereas multi-staging of centrifugals is rather cumbersome for an aero engine.

Extraordinarily high flows can be passed through a small diameter axial flow machine and values of over 25,000 c.f.m. per sq. ft. of total frontal area (including the hub and casing) are not uncommon. Isentropic efficiencies of about 90%, without cooling, are now quite usual under optimum conditions. However, the axial has a number of disadvantages for industrial use and is in fact only likely to be justified in large sizes when flows upwards of 10,000 c.f.m. are required. The manufacture of blading is a difficult and expensive business because of the profile shapes and accuracy required. This becomes less serious in larger sizes as the number of blades required does not vary greatly with throughput. Also in small sizes the aerodynamic performance is poorer and the machine very susceptible to dirt and to accidental damage. Width of characteristics is generally smaller than with a centrifugal. So it seems likely that the axial is likely to be most used where large flows are required, preferably with a reasonably predictable load, such as for example in blast-furnace blowing or high speed wind tunnels. A remarkable example of the latter type is described in Ref. 2. This has a tip diameter of 18 ft. and maximum throughput of the order of 3½ million c.f.m. The performance which was required could only be attained by means of an axial compressor, and even then necessitated the provision of means of altering the number of stages in use.

control of aerodynamic compressors

Because of their liability to surge and the fact that they are used mainly for large flows, when receivers are not practicable, the control of aerodynamic compressors may present rather complex problems. Various different operating regimes may be required from constant pressure with varying flow to constant flow irrespective of pressure, or some intermediate combination of flow and pressure variation. Variable speed drive may or may not be available. A complicating feature is that the performance of aerodynamic compressors is very sensitive to ambient temperature as well as to pressure. Actual detection of the approach to surge is difficult and usually the best that can be done is to limit delivery pressure, making due allowance for likely variations in ambient conditions. Apart from speed variation, the usual control variables are blow-off, inlet throttling or variable diffusers or inlet guide vanes. These are usually operated by some means like the Askania regulator system (the operation of which is described in detail for various applications in Ref. 3).

There is no doubt that more sophisticated forms of control system could be developed which would permit fuller use to be made of the potential performance of compressors of this kind. Such systems would depend on measurements of factors like Mach numbers or flow angles at appropriate points in the machine. So far, the use of aerodynamic compressors has not been sufficiently widespread to necessitate this kind of development for general use.

some remarks on the driving means

Considering the various possible means of driving compressors, there is no doubt that, excluding electric motors, the diesel engine is by far the most economical engine, so far as fuel cost is concerned, in the medium size range — say up to a few hundred horsepower. Above this size range the steam or gas turbine may be an attractive means of driving an aerodynamic compressor. There is, by comparison, little to commend the petrol engine except lower first cost and somewhat lighter weight.

Where weight is really important it is no use trying to use a light weight compressor with diesel drive. The gas turbine is ideal in such circumstances and various proposals have been made, and some tried, ranging from a separate compressor of the vane or Lysholm type driven by a gas turbine, to integrated schemes where the compressed air is bled from the main gas turbine compressor and perhaps boosted in a small high pressure stage. Such schemes are likely to have low overall efficiencies unless complicated by the use of heat exchangers which will somewhat reduce the weight advantage and increase the cost. Consumptions will probably be in the region of 4 c.f.m. per lb. of fuel per hour at 100 lb./sq. in. g. and full load. Weights may be as low as 2 c.f.m. per lb. total weight, giving an improvement over present day portables as great as a factor of 30 or more. However, it is certainly true that there are many problems, such as those of control, to be solved before machines of this kind are available. They will then make possible the supply of large quantities of compressed air power in places otherwise inaccessible to it, and will also be especially valuable in cold climates where the attributes of the gas turbine are particularly favourable.

FOR REFERENCES PLEASE SEE PAGE 489

batch production of piston type hydraulic control valves

A Thesis by

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THE field of application for hydraulic control valves is steadily increasing and the standard of performance demanded becomes more exacting. In this particular treatise the emphasis is on the piston type valve which consists basically of a hardened and ground spool sliding in a cast iron body which, by virtue of the lands in the spindle and the annuli and ports in the body, permit the flow of oil to be directed to the input of various types of hydraulic cylinders whose pistons perform mechanical functions. These valves are illustrated in Figs. 1, 2 and 3. Typical applications are seen in Figs. 4 and 5, but the range reaches far into agricultural, industrial and mechanical handling mechanisation. Excavators and trench diggers, cement mixers and bulldozers, fork lift trucks, are but a few of many.

Fig. 5 shows the Simon hydraulically-operated platform where the bank of valves controls the jack knifing of the upper and lower booms and the swivelling action of the whole in either direction. Although in this case the valves are mounted at the base, this sequence of operation, which can be varied or performed simultaneously, is carried out by foot pedals on the platform but mechanically linked to the valve operating levers. It must be remembered that under such circumstances, where a machine is working continuously for hours, the hydraulic system is subjected to very great strain and, quite apart from design consideration, the production quality of the components must be of a high standard. The multiplication of units for one-man operation can be achieved without much difficulty provided that accurate machining of block faces and "O" ring counter-bores is carefully observed.

The operating pressures commonly required for such applications range from 1,500 - 2,500 p.s.i. and production to this end calls for a very close measure of control in all stages of machining and assembly. For this reason, batch production is found to be a satisfactory method which eliminates selective assembly in the final stages. Since it must be recognised that, with standard machines and under commercial conditions, the direct measurement of the clearances, between piston and valve body, in tenths of thousands ceases to be a practical proposition and must be determined by feel and indicated by static pressure-gauge reading. Further, oil viscosity and temperature are important factors in the successful operation of these valves and, therefore, a final check is required. This can be done by operating the valve at a known temperature and measuring a leakage rate of oil passing the final lands of each spindle and recording this leakage in cubic inches per minute.

materials

Not neglecting the economics of production it is found that, for such purposes, the combination of cast iron and steel will give satisfactory results when careful consideration is given to the selection of material specification. Taking, firstly, the cast iron, the basic requirements are :-

1. complete absence of porosity;
2. a uniform density;
3. a tensility that will withstand deep machining of an irregular pattern with minimum distortion (see Fig. 6);
4. a density of structure such that the edges of machined annuli will remain sharp;

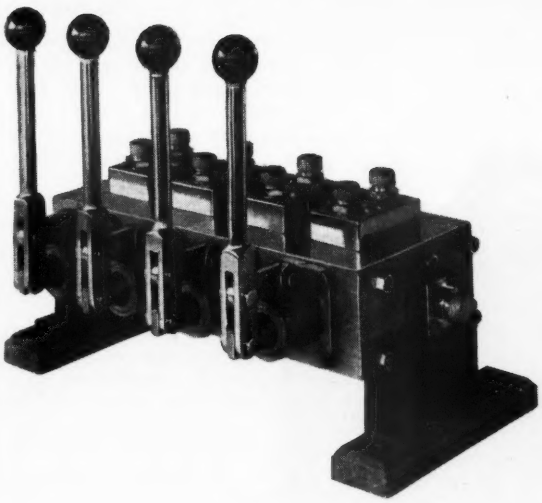


Fig. 1.

5. wear resistance to the point that a skin tends to be formed on the surface, thereby giving long life against the continuously reciprocating action of the hardened steel piston; and, lastly, but by no means unimportant,
6. a coefficient of expansion compatible with that of the steel spindle and such that, under operating conditions ranging between 20°F to 200°F, will not introduce a differential resulting in failure of the valve through either excessive leakage or spindle seizure.

These conditions can be satisfied by the use of a grey iron to the specification B.S.0000/17 1 which has :-

(a) tensile range 17 tons p.s.i.;
(b) Brinell 207/255;
(c) co-efficient of linear expansion .0000056 in.

This is approximately equivalent to a Meehanite of G.C. quality.

Secondly, the steel from which the piston is produced should have the following properties :-

(a) a low content carbon but suitable for case hardening;
(b) machinability;
(c) a microstructure such that a surface hardness can be produced to a Vickers diamond hardness of 740 - 780 or a Rockwell C 60 to 61;
(d) resistance to distortion;

and supplied as bright bars in a cold worked condition. Here, an EN32B (S.14) will satisfy the requirements since the specification 2 shows :-

Carbon	...	...	.10 - .18 max.
Manganese	...	...	.60 - 1.00 max.
Sulphur	...	...	.070 max.

and the combination of manganese and sulphur contents provide an improved machinability. This has a tensile strength of 32 tons/sq. in. and the coefficient of linear expansion may be taken at .00000636 in.

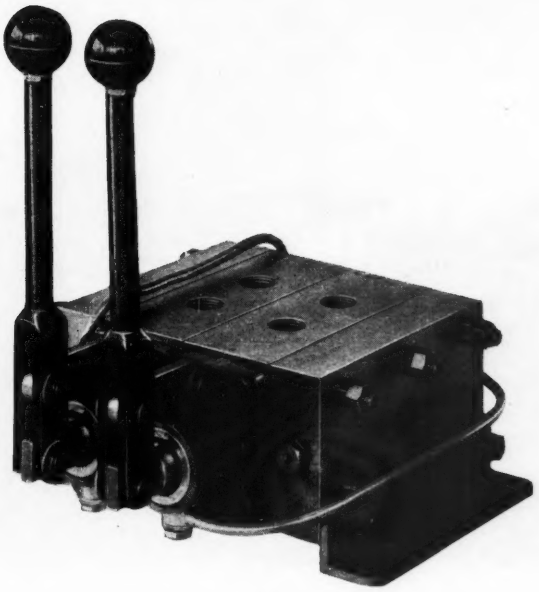


Fig. 2.

which, under normal working tolerances, is compatible with that for the cast iron selected. Other materials used in the overall production such as end castings, rubber "O" seals, springs and the steel operating lever, require no special comment.

breakdown of components and batch sizes

As mentioned earlier, close control of machining and assembly is a prerequisite for optimum performance of the finished product. This in itself, though not an adequate reason for batch production, is supported by the additional factor that the cast iron valve bodies require a period for equilibrium of molecular stress between completion of the heavy deep machining and the production of the final bore. There is also the matching of the ground spindles before the honing and final lapping takes place. It is quite erroneous and futile to presuppose that there

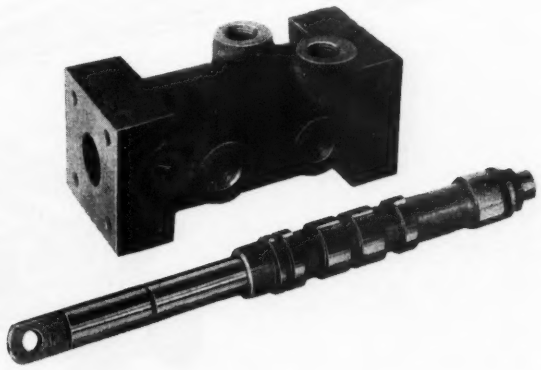


Fig. 3.

Fig. 4.

can be any free interchangeability of spindles even with elaborate methods for control of grinding size.

Neither can the commercial aspect be forgotten inasmuch as hydraulic control valves of this nature, even when complete with cylinders and ancillaries such as pumps and tanks, are usually supplied as original equipment and form part of a much larger machine of disproportionate cost. In practice, therefore, it is found that a batch size between 75 and 100 sets is a convenient quantity to follow through the various stages. The production of fittings and attachments which come under the normally accepted machine limits, and even the rough machining of spindles, need not be controlled in any particular quantities.

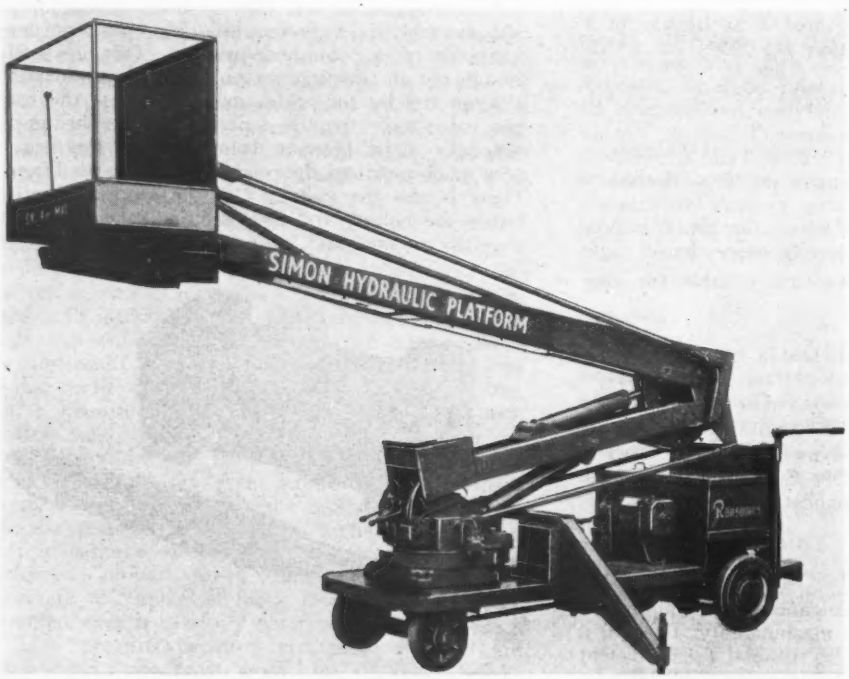


Fig. 5.

production

For simplicity, reference to the equipment involved in the production of the fundamental components is best made progressively when analysing the methods. For brevity and as in the earlier consideration of types of materials, it is not necessary to discuss in detail the production of fittings such as end castings and operating mechanism, since these may be varied to suit different applications and conditions.

The valve body, of which details are shown both in Fig. 6 and Diagram 1, is received from the foundry as a casting measuring approximately $6\frac{3}{4}$ in. $\times$ $2\frac{5}{8}$ in. $\times$ $3\frac{3}{4}$ in. On an Archdale production milling machine running at 50 ft. per minute, these are held in machine vice and slab milled at a feed rate of 2 ft. per minute, the faces being machined in the order — front, back, sides and, finally, ends. A normal allowance of .010 in. is left for surface grinding with the block located on a magnetic chuck and the use of a fixture ensures that the faces are square to each other within the degree of accuracy required. Initially the end faces were ground to the tolerance of $\pm$ .003 in. on the overall length, but this gave rise to the possible introduction of error when boring the annuli in a later operation. For this reason the ends are left after slab milling with a .020 in. allowance for facing on the combination turret lathe at the boring stage 3.

importance of handling

From this point careful handling becomes of paramount importance because, apart from the location in the various jigs and fixtures, blemishes on the faces may cause leakage in the final assembly or distortion of the bore resulting in "sticky" pistons. Either of the two sides (since in final assembly they will not be in face contact) is selected at a datum face and bench marked "A", and the block is located in the composite drill plate with datum face forward. Two holes on each side in turn are drilled $\frac{15}{64}$ in. and reamed and become the master locating points for all subsequent machining and, finally, when fitted with dowels, for assembly. With datum face left and locating in fixture (Figs. 9 and 10) the $1\frac{1}{16}$ in. diameter hole is drilled at 290 r.p.m. and feed of .010 in. per rev.

The boring and cutting of annuli may be done effectively on a Herbert 7B combination turret lathe. The requirements are: firstly, a suitable fixture (see Fig. 11(a)) in which the valve body is located again by the dowel holes and retained by a plate so that the pressure is evenly spread. This is very important as retention by a small pad was found to produce distortion of the bore after release from the fixture. The block is located with the datum face forward for the first part of the operation, i.e., facing, boring and cutting annuli Nos. 1, 2 and 3. Secondly, a boring bar — located in the turret and of sufficient length to engage with a ball race bearing and felt wiper situated in the spindle of the headstock — is fitted with adjustable Ardoloy tip and set to bore at finished diameter less .008 - .010 at a normal speed of approximately 260 r.p.m. and feed

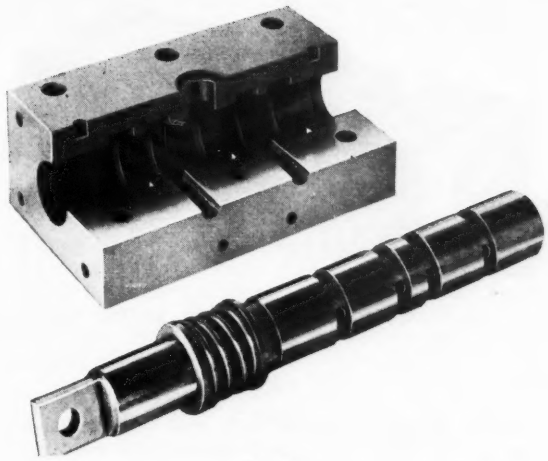


Fig. 6.

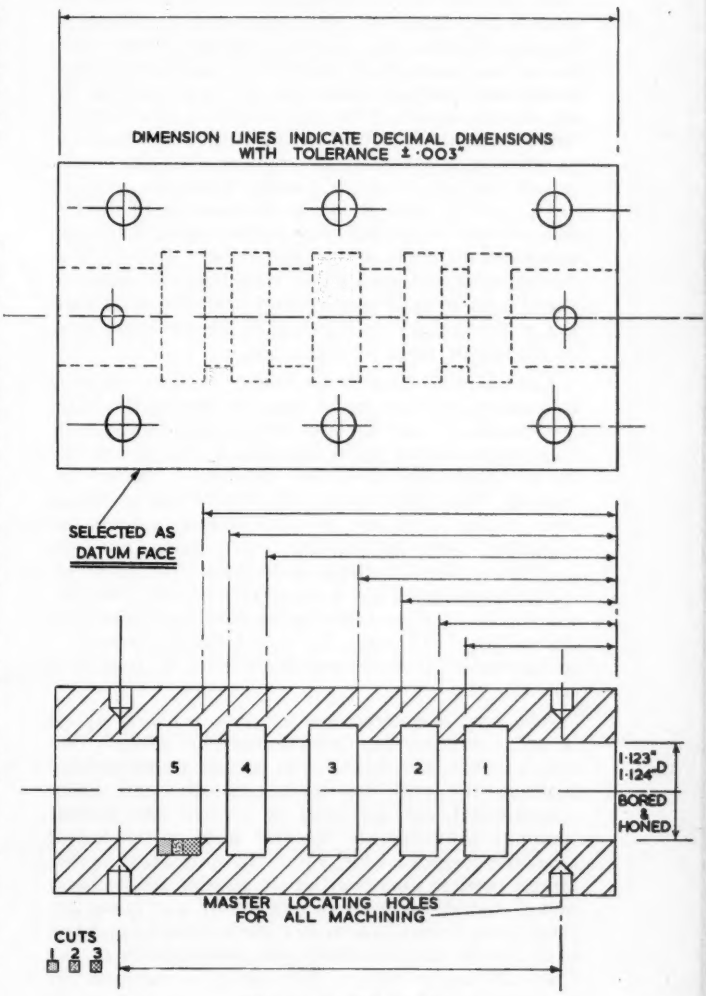


Diagram 1. Valve body.

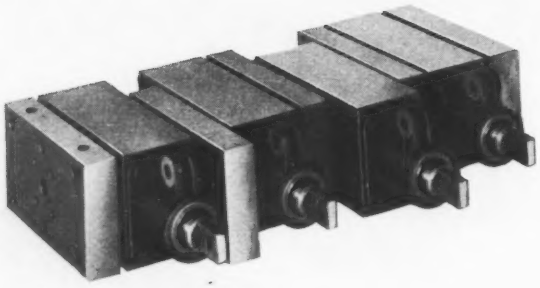


Fig. 7.

.004 in. Thirdly, a cobalt H.S. steel boring tool set up in the front tool post. It will be seen from Diagram 1 that the cutting of the annuli positions must conform to the tolerance of –.003 in. This, of course, is dictated by valve design and the degree of overlap of the lands on the sliding piston. After facing and completing annuli 1, 2 and 3 the block is removed, turned round but not over, so that the datum face is facing the rear tool post. The block is faced with two further annuli cuts. It is found in practice that, when machining valve blocks of this length and bore, it is not possible to obtain sufficient rigidity of the boring tool to allow cutting of the five annuli from one setting. Further, to ensure that sharp edges are maintained, the boring tool ($\frac{3}{16}$ in. wide at cutting edge) is operated in three cuts as shown in the sketch. It must also be remembered that at each cut of the boring tool backlash in the traversing gear of the saddle must be taken out.

Considerable heat is generated in the foregoing operations and it is found that, by leaving the block to "weather" for 14 days before final boring, the subsequent honing and lapping-in of the piston will be an easier operation and produce a better test reading. The inter blocks and effluent end plates, as seen in Fig. 7, require the same degree of finish for engaging faces as for the valve body but the machining after grinding, apart from close attention to the dowel holes, has no peculiarities and calls only for drilling and counter-boring for the location of the rubber "O" rings. Care in handling is equally as important, since mating faces must be free from blemish.

The final operation may be done on such equipment as a Boley fine boring machine. Usually the recommended procedure is to set up a rotating bar between the two driven centres (the tail being synchronised with the head by its own independent motor) and to operate, for cast iron, at the lowest available speed of 1,500 r.p.m. In spite of using the largest possible diameter bar (in relation to the bore) and a carbide tipped tool, the result was quite unsatisfactory because of chatter marks which appeared over a wide range of feeds and varying sizes of cut from .002 in. to .008 in. The use of a diamond tip was considered but had to be rejected on the ground of cost. After much experiment it was found that a very satisfactory result could be obtained by reducing the speed to 525 r.p.m., the feed to .00088 in. per rev., and a depth of cut of approximately .005 in. In the case of the latter figure this is a compromise between a .002 in. cut which causes rubbing and, say, a .010 in. cut which, although producing a good finish, results in rapid tool wear and a tendency to taper. Also it was found necessary to substitute for the bar driven at both ends, a bar driven only from the spindle. This has the added advantage that there is no necessity to remove the boring bar from between the centres to set up each block in the fixture. The fixture, as in previous operations, contains the two dowels for picking up the master holes in the valve body and only very light clamping is required (see Fig. 12). Between the operations of rough and fine boring and because of the weathering period, it is necessary to apply a thin film of oil to the ground blocks but it is interesting to note that any trace of oil entering the bore will reduce tool life in the final operation. For ease of adjustment, the boring tip may take the form of a Microbore tool and under normal conditions with the correct grade of tip, a batch of approximately 75 blocks may be machined without regrinding or resetting.

vertical boring

Although the result produced by a horizontal precision boring machine is of an acceptable standard, vertical boring for this class of work may often give an improved quality. The basic argument in its favour is that the boring bar, driven from the bottom end and guided by a travelling centre at the top, produces no wear through side strain on the bearings and the whole thrust is taken at the bottom. Another advantage is that swarf clearance presents no problem whatsoever. For cast iron, this type of machine operates at about 1,500 r.p.m. with a feed of approximately .0005 in. per rev. Currently, an investigation is being made into the possibilities of using a superfinishing roller mandrel because, in theory, there

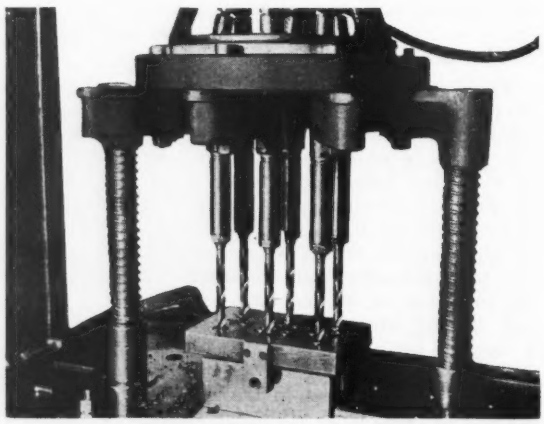


Fig. 8.

would then be no necessity for honing. There is a claim by the manufacturers that the surface is compressed to the extent that there is a 50% strengthening over the core hardness and an excellent surface finish. Although it is said that splined holes can be finished machined by this process, the possible main disadvantage yet to be proved is that there might be some breaking down of the edges of the annuli, or a distortion of the clean sharp corners so essential for the successful operation of the valve piston. The Berlin Material Testing Bureau claims that, in the case of grey cast iron, microscopic checking has shown that all the ridges of the surface have been fully flattened and that it becomes highly wear resistant with good sliding properties. If the experiments prove successful, not only would control of bore size be more accurate but production time would be reduced 4.

The piston, or valve spindle (Diagram 2), made from S.14 material is turned to grinding size on a No. 3a Ward, and the flats milled. Carburising to a depth of .030 in. follows and then, between centres, the annular grooves are cut and the ends drilled and tapped. Cross holes, too, are drilled at this stage. Accuracy is required in the milling of the metering slots and the turning of the 14 small "V" grooves. The purpose of the former is to enable the valve to be "cracked" on operation more easily than would be possible with the land passing over the valve body annuli at full diameter. The function of the small grooves may not at first be apparent. At high operating oil pressures the sudden opening of a port will cause a side thrust on the piston which forces out the oil film and gives a virtual metal to metal contact coupled with a distortion along the axis which, though minute, is sufficient to cause a sticking piston. The grooves, therefore, ensure that there is always a balance of oil pressure, after the momentary initial kick, and the distortion is eliminated. These grooves, however, must have sharp edges since a radius or chamfer, however small, would encourage any particle or foreign matter in the oil to try to ride on to the lapped surface of the piston land and again result in distortion or leakage.

Hardening may be carried out by induction method if such equipment and jigging is available on, say, a Delapena high frequency machine. This is perhaps the best when quenching can follow continuously behind heating and gives a result very free from distortion. Alternatively, the normal method can be applied :-

Heat to 860°C - 880°C and oil quench.
Reheat to 760° - 780°C and water quench.
Follow by tempering at 165°C - 175°C 5.

The grinding operation, which is quite straightforward, is carried out on a Newall type XL plain cylindrical grinding machine after centred brass plugs have been screwed into each end of the piston. A white Bauxilite wheel with a specification of UNI/WA/70 MV is suitable and will produce a 10 micro inch reading. Here the tolerance on diameter is .0005 in.

assembly

The first phase is the honing of the valve body and the lapping in of its piston which then ceases to be interchangeable. There are various types of machines but the Delapena, fitted with a horizontal

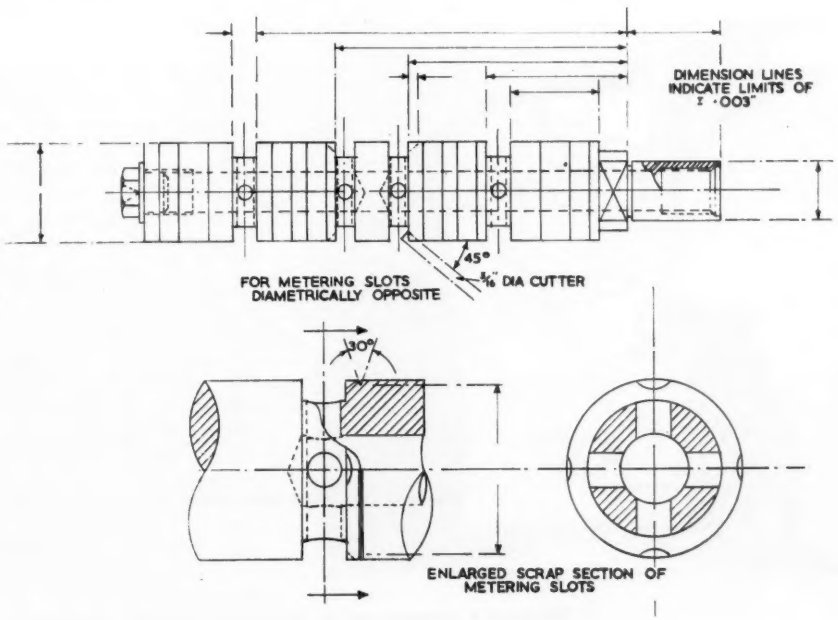


Diagram 2. Valve piston.

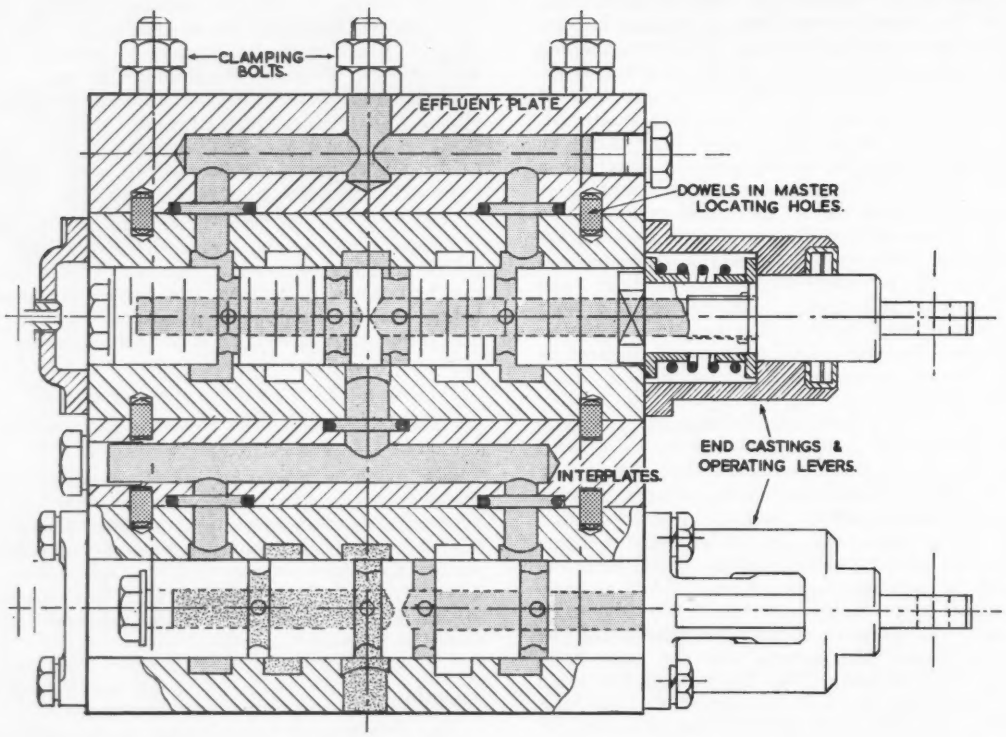


Diagram 3. Valve assembly — part section.

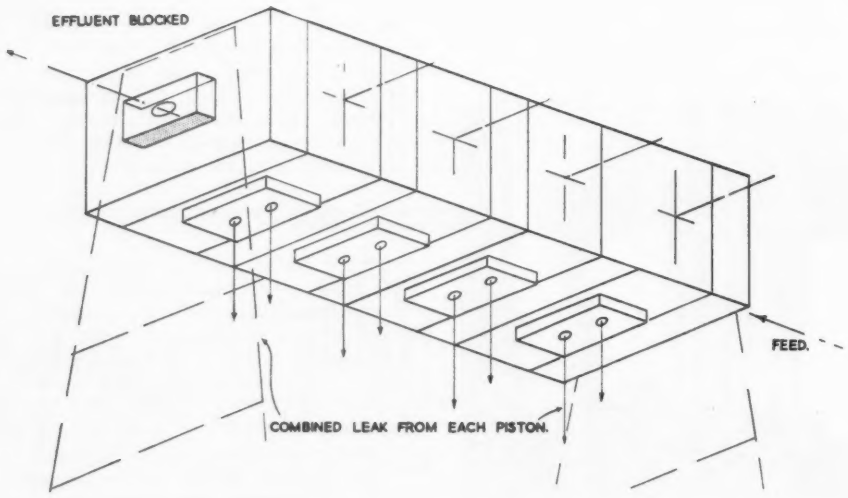


Diagram 4. Arrangement of assembly to measure leak rate.

mandrel and foot controlled for speed, is a suitable type. Honing fluid is applied continuously to the stones which revolve up to 140 r.p.m. and the valve body is supported and reciprocated manually. Although the practice of honing generally can be carried out mechanically, it is found that for this class of work the operator's skill is a factor, since the result is better when the mandrel is not rigid. In this operation, any " bell-mouthing " of the bore must be avoided and the honing is more of a smoothing process rather than removal of metal. A piston in its finished ground state is introduced into the bore and slowly lapped in by holding the piston by the tongue in a vice and working the block on to it. The honing stones in the first part of the operation will have left sufficient residue of abrasive material in the honing fluid, so that no other is necessary. When it is considered, by feel, that the correct fit has been obtained, the block and piston are washed thoroughly in paraffin and tested against a static oil pressure. In this instance there is a port to each half of the block (see Diagram 3) and with the piston in the neutral position a pressure of 400 lb. p.s.i. is applied. This figure is derived experimentally. If the piston will sustain a higher figure then it will be found that on assembly of all the units, there will be a tendency for the pistons to stick. Conversely, a lower figure will result in a leakage rate greater than permissible.

The valve blocks with their individual piston may now be assembled sandwich fashion with the inter plates and the oil sealing rubber " O " rings (after tapping in the locating dowels) and end castings, springs collar and operating levers. The six clamping bolts are passed through the whole assembly and the tightening of the units should be done with a torque spanner and in the same way as an engine cylinder head is pulled down. Over-tightening always produces distortion of the blocks and pistons.

testing

Finally, there remains the testing of the assembly. As mentioned earlier, the leak rate is the first requirement. The complete block of four valves is mounted as shown in Diagram 4 with all spindles in the neutral position. With the effluent port blocked the oil pressure is applied at the feed side. It flows through the common circuit and bifurcates at each spindle. A thermostatically controlled immersion heater is fitted to the supply tank and raises the oil to 180°F. This is drawn through a four-cylinder piston pump and the circuit is fitted with a relief valve, pressure gauge and control valve. The combined leak from both halves of each piston is measured and, for this type of valve and its particular application, must not exceed half of 1 cu. in. per minute. This may seem exacting, but the successful operation of the machine which these valves control depends on the immediate response and unfailing action of the pistons in the cylinders. The main static load of the machine is usually left " standing on " the oil pressure and the valve piston and, therefore, any excessive leak rate causes the load to drop.

The leak rates are recorded and entered on to a test certificate which accompanies the finished product

Test Certificate No.....

Static Test Particulars for Valve Type No.

Leakage Rate — Cubic Inches per Minute

Valve Serial No.	*Block No.4*	*Block No.3*	*Block No.2*	*Block No 1*	*Date*
EA.123	Nil	.5	.25	Nil	
124	.25	.5	.5	.25	etc.

Note: With feed ports uppermost blocks read from left to right.

Pressure: lb./sq. in. — 1,500.

Oil used during test: Wakefield Icematic Light — Temperature 180°Fahrenheit.

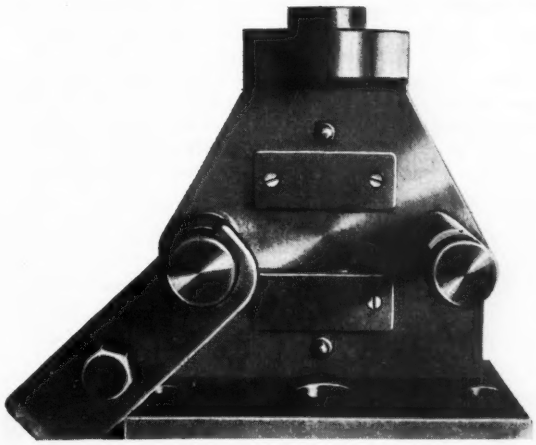


Fig. 9.

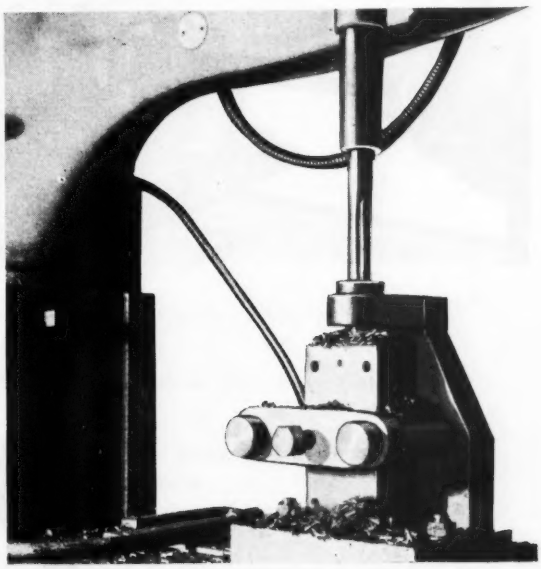


Fig. 10.

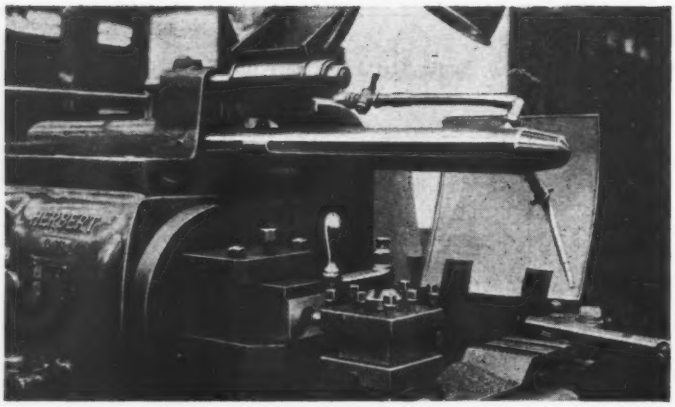


Fig. 11 (left).

Fig. 11(a) (right).

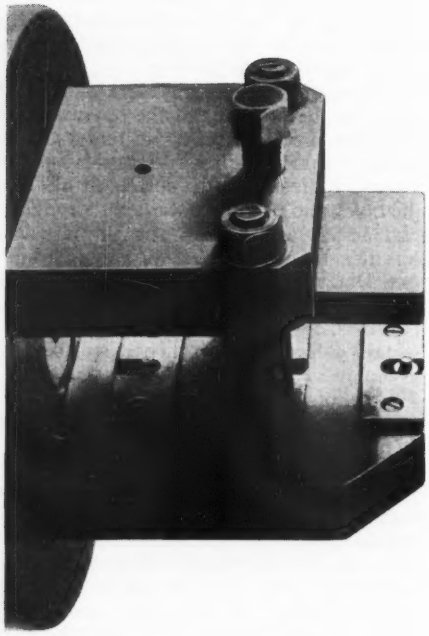


Fig. 12 (left).

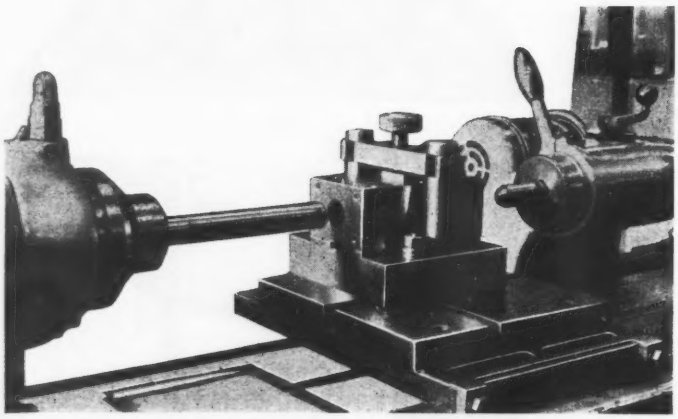
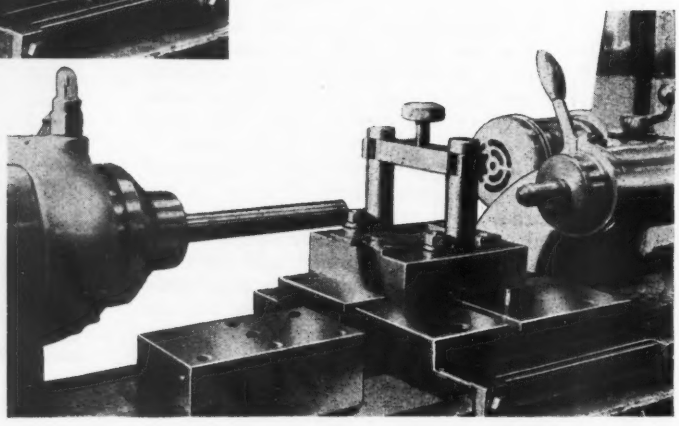


Fig. 12(a) (right).



If it is found that for any particular valve block the leakage is excessive, there is no alternative but to dismantle and replace with another block and piston. It may now be realised that the close control applied to all the earlier operations was necessary in every detail if a low rejection rate is to be maintained. Although the initial material cost is low, the machining and labour have considerably increased its value.

For the running test, a bank of four double-acting cylinders are piped in and the effluent side of the complete assembly is fed back to the oil reservoir. The oil is allowed to circulate freely until such time as the whole assembly has been lifted in temperature to approximately 150°F. The choice of oil is important and experiment shows that an Icematic Light will fulfil the conditions, since the usual requirements for this class of work call for chemical stability, high lubricity and the correct viscosity. The ideal oil, if such a thing existed, would be one whose viscosity was invariable over a range of temperatures. There must be no oxidation which might form sludge and, under working conditions, the film strength should be adequate to prevent metallic contact. In the earlier mention of hydraulic lock the film, though microscopic, must be assisted by the balancing "V" grooves. During testing, cleanliness of the whole system must be observed as any grit or abrasive material will score the rubbing surface. Therefore, the reservoir tank or the oil circuit is fitted with removable filter units. During the functional test the spindles are operated singly, simultaneously and in any combined sequence. The relief valve in the circuit remains at 1,500 p.s.i. but there is always the higher flick pressure which cannot be measured on normal pressure gauges. Where necessary, in the prototype stage these figures may be obtained on electronic equipment.

If care in the lapping in and assembly of the blocks has been exercised there will be no sticking spindles, but if a spindle fails to return to neutral instantly on release, the whole must be dismantled and the failing block replaced. In addition there must be no leaks from between the inter or effluent plates nor from end castings or ports. Detection of leaks is often made easier by introducing a red dye into the oil circuit. After test the assembly is drained and all ports are sealed with either masking tape or dust caps.

conclusion

The foregoing methods apply to merely one variety of piston type hydraulic control valve and the design in this case, but not the production method, is subject to a British Patent Application. Many other valves, even of the spool type, do not require such accurate control in their production but it is usually found that they are not required to operate at such high pressures. Even so, close control of finish boring and grinding improves efficiency, lengthens life of operation and reduces the rejection rate.

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3. Syd Abrams Ltd., Manchester — Milling and Surface Grinding.
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DIARY FOR 1958

27th - 31st August ...	**Annual Summer School,** Ashorne Hill, Warwickshire. (See Supplement to this Journal.)
13th 14th 15th October	**Materials Handling Convention,** Brighton (see Supplement to this Journal).
29th October	**Annual Dinner of the Institution,** Dorchester Hotel, London.
11th December	**The 1958 Sir Alfred Herbert Paper,** to be presented at the Royal Institution, London. Speaker: **Sir Cecil Weir,** Past President of the Institution. Subject: **"The European Common Market — Its Origins and Implications".**

The Heating and Ventilating of Factories

a review of developments and methods

by F. CARTER

presented to the Ipswich and Colchester Section of the Institution on 13th December, 1957

IN discussing this subject, I shall deal with the forms most commonly used and, in addition, review certain of the post-War developments in this branch of engineering.

Before considering methods of heating or ventilating, we can first examine the requirements of the Factories Act in respect of Space Heating which states, and I quote from the Act:

> "In every workroom in which a substantial proportion of the work is done sitting and does not involve serious physical effort, a temperature of less than 60°F shall not be deemed, after the first hour, to be a reasonable temperature while work is going on, and at least one thermometer shall be provided and maintained in a suitable position in every such workroom."

It will be seen that the wording of this Act is very loose, excepting insofar as sedentary workers are concerned and, because of this, the standards of heating in certain factories fall far below what might be reasonably expected in order to obtain efficiency from the workers.

Prior to the last War, there were a number of factories where the heating fell very far short of the Factories Act and it was perhaps fortunate for factory owners that the Factory Inspectors seldom exercised their full powers. The War years necessitated increased production in our factories and managements realised that environment played a large part in their production statistics. In general, factories were employed to capacity and greater finance became available during the War for improvements. The result of this was that many executives spent considerable sums of money on welfare facilities for their employees in the way of canteens, toilet blocks and First Aid stations. In addition, they made greater improvements in their factories during the few years of the War than had taken place over the previous 20 years. These improvements covered heating, ventilating, and lighting. An examination of a modern factory shows a high standard of heating and, where necessary, ventilating. Following the War, it is true to say that in general there has been a full state of employment in most of our factories, which has enabled large numbers of employees to choose the employer for whom they would work and, in making this choice, they have given consideration to the factory amenities as well as the wages they would receive for their labours.

It is to a large extent due to these factors that one now seldom sees factories being heated by slow combustion stoves and other even more antiquated hit-and-miss methods.

the ideal installation

We therefore come to the question "What is the ideal installation?". Unfortunately the answer is still — "there isn't one". The true answer is — one that provides the greatest comfort effect for the minimum capital cost and, coupled with this, the lowest costs in fuel and maintenance.

We must therefore consider various ways and means and then decide which is the right one for a particular factory. I stress "for a particular factory", because what might be right for one factory might not be right for another. Such factors as periods of occupation, type of work undertaken, availability of the various types of fuel or energy and what is most important, the constructional details of the factory, must be taken into consideration.

Before deciding on the method of heating a factory it is first of all necessary to determine the heat losses of the building. This is known as the "computation of the heat requirements" and is a fairly long and laborious process. Heat losses from a building take place through the walls, floors and roofs, and their extent is dependent on the nature of the building materials forming the construction. It was quite common practice before the War to see factory walls and roofs constructed entirely of corrugated asbestos or iron. Although capital cost is of considerable importance, I find it hard to believe that the people responsible for building such premises appreciated that the heat loss was approximately 50% greater than if they had built the whole place of ordinary glass. The heat loss factor from unlined corrugated asbestos is approximately 1.5 and from glass 1.0.

To form some idea of the seriousness of this, I have taken as an example an engineering factory in the Eastern Counties which has approximately 300,000 sq. ft. of roofs and walls constructed from corrugated asbestos sheeting. The heat loss figures for unlined asbestos sheeting is approximately three times that of lined sheeting, and by applying insulation to these areas of corrugated asbestos a saving in fuel cost of approximately £6,000 per year could be obtained. This is based on using 220 seconds fuel oil. The cost of applying insulation could be written off in fuel saving in approximately five years.

Whilst in a democratic country any Government legislation which may restrict freedom of action is resented, I most heartily welcome the proposed Bill recently before Parliament which gives certain powers to local authorities, in the way of requiring minimum standards of insulation to be provided in buildings before the plans will be passed. The industrial economy of this country depends to a large extent on our ability to use wisely our limited resources of coal, and any means which will prevent the indiscriminate waste of fuel must, I feel, be welcomed by all sound-thinking people.

To the losses through the structure must be added the amount of heat required to make up that lost due to infiltration. By that I mean losses through doors, ridge and eaves, and all other leakages in the structure. In a large factory the cubic capacity can be enormous and, therefore, when we speak of only one or two air changes per hour, it can represent high costs in capital for the heating plant and, in addition, perpetually high running costs. The answer to this is for factory executives to take whatever steps are practicable to reduce leaks in their buildings, especially at such places as the ridges and eaves and through large door openings. It is quite common to see employees using large doors when, if smaller doors were provided, better conditions in the factories would be obtained, with the use of less fuel. Steps should also be taken by executives to provide electrically operated roller shutter doors where such large doors have to be used intermittently for the passage of goods.

common forms of fuel

Having completed the heat loss calculations, one must then determine the form of energy that is to be used to provide the heating. The most common forms of fuel used at present are coal, oil, gas and electricity. In the 1930's this country had an excess of coal over its requirements, resulting in unemployment in the mining industry at various periods. In an attempt to counter this the Government have, from time to time, varied the rate of tax on imported oil fuel, with the result that building owners were on several occasions changing from oil to coal and then back again to oil when the tax was reduced.

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Fuel	*Price*	*B.T.U.s per d. at 100% efficiency*	*Operating efficiency*	*B.T.U./d. at corrected efficiency*
COAL	£6 16s. 0d./ton	16,500	65%	10,700
OIL (220 sec.)	12⅞d./gallon	13,700	70%	9,600
GAS	20d./therm	5,000	100%	5,000
ELECTRICITY	1½d./unit	2,275	100%	2,275

Fig. 1. Comparative costs of fuel.

It seems that in our present economy we shall be unable to meet all our requirements in the way of solid fuel and, because of this, the Government have encouraged high capital development schemes during the post-War years in British oil refineries. Knowing this, it seems that short of an international catastrophe we can — in my view — accept oil as a permanent contribution to our fuel requirements. Gas and electricity, being by-products of coal, make further demands on our limited coal resources. Those responsible for the sales of oil, coal, gas or electricity are usually biased in favour of the particular form they have to sell and the consumer is therefore all too often confused with figures prepared by these various people, all of which show that their particular fuel is the right one to use. There are many factors to be considered in addition to the actual comparative cost of obtaining a similar number of heat units for a like amount of expenditure. Such factors are labour in attendance upon the plants, flexibility to meet the particular requirements of the particular building, capital costs in forming boiler houses, chimneys, and so on. All these can strongly influence the final decision on the most suitable fuel to be employed.

I shall now attempt to set out figures in relation to the various grades of fuel without suggesting that:

(a) the cheapest is always the one to use; and
(b) the most expensive the one never to be used.

There are cases for the use of all fuels, and we can only reply upon sound advice and good judgment being exercised in determining what is the best solution to a particular problem (see Fig. 1).

The figures I shall use are, in the first case, based on 100% efficiency being obtained from all fuels and show the respective B.T.U.'s obtained per penny. It is obvious that 100% efficiency cannot be obtained when burning coal or oil, and unless direct gas fired space heating equipment is used, the same is true for this fuel. In actual fact, makers of direct gas-fired space heating equipment do not usually claim 100% efficiency, but the figure is so close to 100% that for the purpose of discussion 100% efficiency is being used in this case. In the case of electricity, 100% efficiency is used.

boiler plants

I now propose to deal briefly with the subject of boiler plants. There are many installations throughout the country where the boiler plants are in the sole charge of an odd-job man, or perhaps one of the non-technical office executives. In doing this it must be assumed that the building owners are completely ignorant of the money that can almost literally be poured down the drain. The operation of a boiler plant of any proportion is a skilled job, and if the best service is to be obtained, then the right class of man must be employed and this can only be done if the proper rate is paid for the job. A few extra hundreds per year in wages to the proper staff can easily be saved in fuel economy and the maintenance costs of the plant. Instrumentation is important, but here again, it is of little use spending money on these if no one properly understands what they all mean — and it is true to say that this happens on some jobs where the plant has cost the building owners many thousands of pounds. Any building owner who has a large boiler plant should consider most seriously whether he has the best possible staff in charge. He can, in addition, get expert opinion on the efficiency of the plant from the N.I.F.E. organisation.

Boiler plants can broadly be divided into two groups — water and steam — and these two groups again divided into high or low pressure water and low and high pressure steam. Low pressure water installations are those where the operating

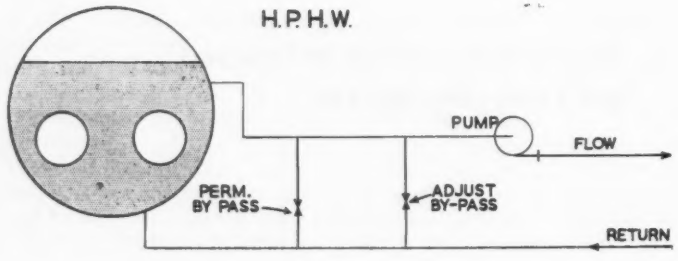


Fig. 2.

temperature is below approximately 200°F and are generally suitable for the smaller size factories. This system usually comprises cast iron boilers and radiators.

High pressure hot water was little known in this country before the War and it was the enormous building projects built during the War that first gave scope for this type of installation. I shall endeavour to explain briefly the principles of this type of installation. It is readily appreciated that at normal atmospheric pressure water boils at 212°F and, at the same time, we all remember in our elementary training being told that at higher pressures it does not boil until higher temperatures than 212°F have been achieved. Thus at a pressure of 150 lb. per sq. in. water boils and is converted to steam at approximately 367°F. This is the fundamental principle of high pressure hot water. On this basis, if a boiler plant is operated at 150 lb. per sq. in. it is possible to circulate water at a temperature slightly below that corresponding to the boiler pressure — thus at 150 lb. per sq. in. water is usually circulated at about 15°F below the corresponding temperature, making a flow water temperature of 350°F. Fig. 2 will, I hope, make the principles easily understood.

The boiler used for H.P.H.W. may be of any of the usual types used for steam raising, providing sufficient provision is made within the boiler itself to take up the severe expansion of water volume within the whole system that takes place when increasing the temperature from cold to the high operating temperature. In boilers of the shell type, such as the "Economic", sufficient space is usually available in the steam space above the water line, but in some types of boilers it is desirable to provide a large expansion drum.

In certain factories steam is a necessity for process or other works, but this does not necessarily mean that separate boilers must be provided to deal with the high pressure hot water for heating. It is common practice to operate a battery of steam boilers and from these same boilers provide steam for process work and high pressure hot water for heating purposes.

advantages of high pressure hot water

Why is it that high pressure hot water has become popular in the last 15 - 20 years and so often supersedes steam for factory heating purposes ? The main reasons are as follows :-

1. Steam is quite inflexible in obtaining varying temperatures without varying the pressure. In space heating work, variations in temperature of the heating medium are the main method of obtaining varying outputs from the heating installations consistent with variations in external temperature. When it is realised that a heating system is usually designed to obtain a temperature of 60°F in the factory when 30°F outside, i.e., a 30°F rise above external temperature, it will be seen that when the external temperature is 45°F, only a 15°F rise is required, which is equal to half the normal output. With steam as the heating medium it is often impracticable to vary the steam pressure, with the result that the buildings are overheated unless expensive automatic control systems are used. Even with automatic controls which can cut off the steam to the heating appliance, this is not always practicable because of the sudden reduction in load on the boilers. With H.P.H.W. it is possible to vary in an easy way the water flow temperature to the heating system, simply by an adjustment of valves in the boiler house, which increases the proportion of return water diverted back into the flow main. Thus, if it is possible to follow more closely the output of the system to match the demand occasioned by the variations in external temperature, it will bring about major economies in fuel consumption.
2. The maintenance of steam traps is avoided. On large installations, employing in some cases hundreds of traps, it can reasonably be said that unless someone is continually watching for faulty traps, there is a heavy loss of fuel taking place.
3. The observance of levels of the mains — which is so important with a steam installation — does not present anywhere near so many problems with H.P.H.W.
4. If high temperatures are used for the flow to the systems, it is possible to allow for drops in temperature of up to approximately 100°F between the flow and return mains, and this brings about economies in the sizes of the distributing mains and consequent insulation.
5. On large installations the capital costs of a H.P.H.W. installation are generally no more, and often less, than a steam system and provide flexibility of control that is quite unobtainable on steam systems.

I will now deal with a number of various ways of heating factories and briefly touch upon the respective merits or otherwise of the particular systems.

Earlier in this Paper I stressed that a system which might be right for one factory could be wrong for another and if, therefore, it appears that I favour or criticise a system, it must not necessarily follow that there is a standard solution to all our problems.

Heating of factories in the early part of this century mainly consisted of coke stoves, steel or cast iron pipes or elements suspended at high level or placed around the external walls. These pipes generally were fed with hot water at about 180°F, or steam at about 5 - 15 lb. per sq. in. When these pipes were placed at low level around the walls they were often ineffective because of benches, and when at high level below the trusses equally ineffective because so much of the heat dissipated was lost through poorly constructed roofs.

There were few variations in the methods of factory heating for the first 25 years of this century, until developments commenced with various ways of passing steam or water through elements and using fans for blowing air across the heated elements, which materially increased the rate of heat transmission. Little or no science was applied to these principles and, as can now be expected, the results were in general equally as uncomfortable for the factory employees as they had previously experienced, because they were either in very cold spots or subjected to what almost amounted to hurricanes of hot blasts.

unit heaters

It is from these early experiments that what we now know as " Unit Heaters " materialised. Although the early unit heaters were a considerable improvement in their constructional details over the improvised types, the heating engineers had little basic data upon which to design a satisfactory installation.

Let us consider, briefly, the factors which effect the design. As I have previously mentioned, the heating engineer must first of all calculate the B.T.U. requirements, to maintain a specified temperature inside the factory under specified outside temperature conditions. Makers of Unit Heaters initially produced catalogues of unit heaters with the units having ranges from approximately 20,000 to 200,000 B.T.U.'s per hour and it was left to the heating engineer to guess how many of a particular size he should use to achieve the desired conditions inside the factory. As can be expected, the price factor was all too often considered, which entailed the minimum number of units being installed. So many unsatisfactory unit heater installations resulted from this haphazard method, that it became obvious to the manufacturers that they must prepare and publish data containing much more detailed information.

Factors which determine the choice of a unit heater from the makers catalogues are :-

1. Duty of the unit in B.T.U.'s per hour under specified conditions of the air temperature entering the unit before it is heated.
2. Temperature of the air after it is heated.
3. Volume of air handled by the fan.
4. Velocity of the air leaving the outlet grills or louvre.
5. Degree of silence obtainable.

It is a combination of the leaving air temperature, air volume and velocity that determines the height at which the unit can be mounted and the floor area that can be effectively dealt with. The higher the leaving air temperature the greater the chance of the warm air rising into the roof space, resulting in little benefit to the factory operatives and severe wastage of fuel.

Although initially it may appear simple, it can be said that the design of a satisfactory unit heater installation is quite a problem, and factory executives should beware of assuming that the cheapest price for a particular installation may give them satisfactory results. Money which may be saved in initial capital expenditure can be spent many times over in high running costs, coupled with constant complaints from their employers.

use of town gas

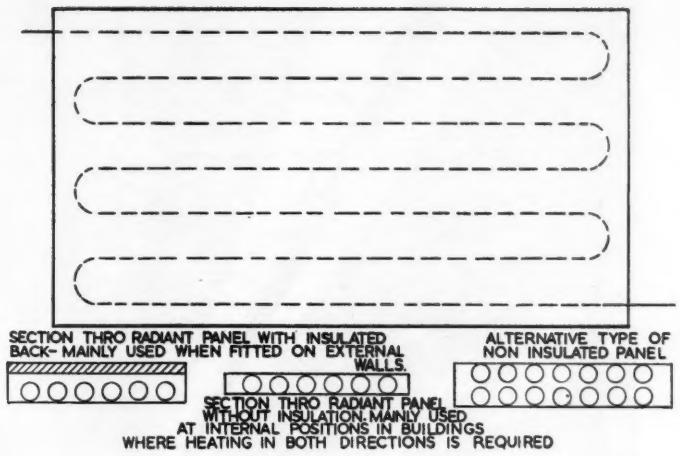
Continuing this review, I wish now to deal with the developments in factory heating using town gas. In the early 1930's the various Gas Companies started a major campaign to promote the use of gas for space heating. As far as I am aware, they were the only people who were offering to provide energy for heating a building at a fixed sum per annum without regard to the amount consumed. The staff of these Gas Companies made their own calculations and estimations of the gas that would be used and the Companies were prepared to enter into contracts with building owners, on a fixed basis. The Gas Companies had a say in the form of heating to be used and the degree of automatic control to be provided. This, of course, was a revolutionary idea in heating, and several installations of a major scale that had employed other fuels changed over to gas. Other Gas Companies offered gas at a price which was really attractive to the factory owner and, taking into regard the saving in labour costs, there is no doubt that in many cases the factory owners made a right decision in using gas.

Gas can be used in several ways, including boiler plants or direct gas-fired space heaters, such as the luminous radiant types. Obviously, if appliances could be used that had no flue losses these were the most effective and, because of this, one saw so many luminous gas heaters being used. It was perhaps unfortunate that, coincidental with the development of these gas radiant heaters, there were so many factories that had so little insulation applied to the structure. Because of this and insufficient natural ventilation, it was possible to see installations where severe condensation occurred, thereby causing rusting of steel products and other problems.

There is, in common with most other forms of heating, an undoubted place for direct gas-fired appliances in factory heating. They are cheaper to install than any of the orthodox forms of water or steam heating, they can quickly provide comfort conditions after being lit, and are especially suitable where, owing to rates of high air movement, radiant heating is the only satisfactory way of dealing with a particular project.

When gas was sold by various private companies there were wide variations in the gas tariffs, but since nationalisation of the industry there seems to be a general levelling up of the tariffs, with the result that it is not now possible to see certain Area

Fig. 3.


SECTION THRO RADIANT PANEL WITH INSULATED BACK- MAINLY USED WHEN FITTED ON EXTERNAL WALLS
ALTERNATIVE TYPE OF NON INSULATED PANEL
SECTION THRO RADIANT PANEL WITHOUT INSULATION. MAINLY USED AT INTERNAL POSITIONS IN BUILDINGS WHERE HEATING IN BOTH DIRECTIONS IS REQUIRED

Boards offering gas at really low prices. Because of this, I think it would be fair to say that the demand for gas for space heating is falling off, whilst demand for other fuels, such as oil, is increasing.

a fundamental development

With the outbreak of War little further development took place in the methods of space heating, except that during the War years considerable development took place in the employment of high pressure hot water for very large industrial premises. This, however, was only a change in the heating medium from steam to high pressure hot water, and not a development in the methods of heating. It was in 1945 that a fundamental development took place in factory heating — in the form of radiant heating.

The first installation was at a factory in Lincolnshire, which had such an assortment of ways of heating a factory that it might almost be termed a "Heating Engineers' Museum". There were water and steam pipe coils at high and low level, water and steam unit heaters at high and low level, and to complete the collection, gas radiant heaters. The management and employees were not satisfied with any of the systems and were anxious to find a solution to their problems. A firm of heating engineers recommended radiant heating. Their proposals consisted of the fitting of radiant panels, 8 ft. × 4 ft. in size, at about 15 ft. centres, around the external walls of the building and against the columns of intermediate bays (see Fig. 3). These units were to be mounted so that the bottoms of the panels were about 9 ft. off the floor. The heating medium proposed was high pressure hot water operating at about 350°F.

The heating engineers had complete confidence in their proposals, but the management were naturally sceptical as the heating engineers could not show them in use an installation similar to that proposed. So confident were the heating engineers that, at a meeting with the management (which, incidentally, took place on VE-day), they offered to install this system in the first section of the works and if after 12 months the management and the employees were not satisfied, they would remove it and install in its place any other system which the management might choose. After 12 months use everyone was so pleased with the results that, over a period of years since the first trial installation, all the other types of heating have been removed and replaced with this form of radiant heating.

The old story that one cannot have a Rolls-Royce for a Ford price is true with heating and radiant heating, in the form described, is substantially more costly than unit heaters and other similar types of heating. Nevertheless, this Lincoln factory has been a successful guinea-pig and following inspections by numerous factory executives, the development of radiant heating has increased enormously in the post-War years, so much so, that manufacturers of unit heaters — who previously had claimed almost Utopian conditions with their products — are now amongst the largest manufacturers of various forms of radiant heating.

Coupled with the improved conditions in the factories, it has been established that the running costs in terms of fuel and maintenance are appreciably less than with unit heaters. The life of a radiant heating system is also longer than that of a unit heater installation, as there are no moving parts in the form of fans and motors.

Whilst on the subject of radiant heating, I would like to deal with a further development in this field, consisting of continuous strips of radiant heating as opposed to the 8 ft. × 4 ft. units previously mentioned. This strip system consists of continuous lengths of steel pipe suspended below the trusses or fixed around the walls, and to these pipes radiant

Fig. 4. Radiant strip heaters fixed to roof trusses in a factory.

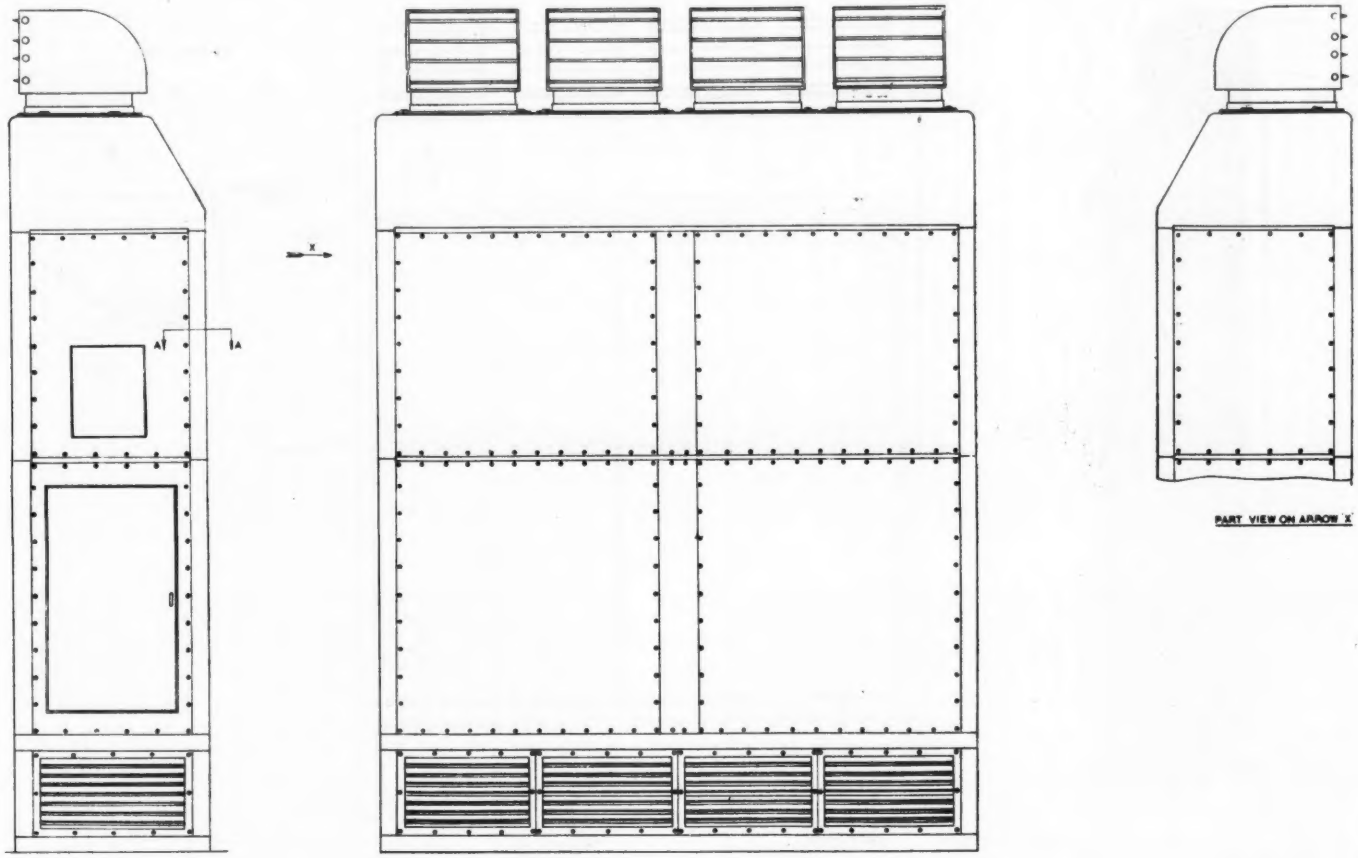
plates are attached. The pipes are usually about $1\frac{1}{4}$ in. nominal bore attached to corrugated aluminium radiant plates about 18 in. wide. A special bedding compound is used to obtain good adhesion between the pipes and the radiant plates, and to prevent loss of heat from the back of the plates, high efficiency insulation is used sandwiched between the radiant plates and an outer sheet steel encasement. Here again, this system has recently been used in a factory extension where previously unit heaters were employed in the original works and everyone is full of praise for the results obtained, whereas they had been highly critical of the unit heater system. Fig. 4 shows these radiant strip heaters fixed to the underside of roof trusses in a factory.

A further interesting development in the post-War years has been in the form of self-contained oil, coal or gas space heaters (see Figs. 5 and 6). These vary in size from approximately 200,000 B.T.U.'s per hour to 1,500,000 B.T.U.'s per hour and consist of a unit comprising oil, coal or gas burning equipment, a heat exchanger and a fan for discharging the heated air into the works. They are delivered to the factory as a composite unit and need only fuel and electrical connections and a flue. No one, I believe, would suggest that these are an ideal way to heat a factory, but they are cheap in initial capital costs compared with the more orthodox forms of heating — especially when including the cost of constructing a boiler house and chimney. They are particularly suitable for large open space type factories and, in such circumstances, it is desirable to obtain the cheapest grade of fuel — which is usually 200 seconds fuel oil as this is approximately 25% less costly than the lighter grade known as gas oil.

There is a large number of these various types of units on the market and, in my view, the greatest care needs to be exercised in the choice of such equipment, otherwise the cheapest in initial cost may not prove to be the cheapest in the long run.

floor heating

There is nothing new in floor heating which was, in fact, first practised by the Romans. Floor heating can be by means of underground warm air ducts, generally following Roman principles, and as now applied in some cathedrals, or by means of embedding low temperature water pipes or electrical elements into the concrete floor slabs. The number of installations using low temperature water is comparatively few, owing to their high capital costs. Such systems have mostly been used in aircraft



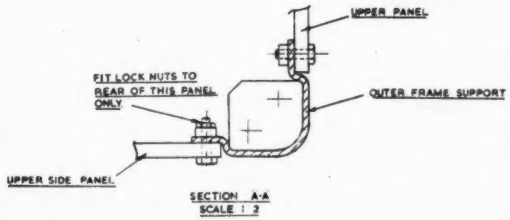


Fig. 5. G.A. heater.

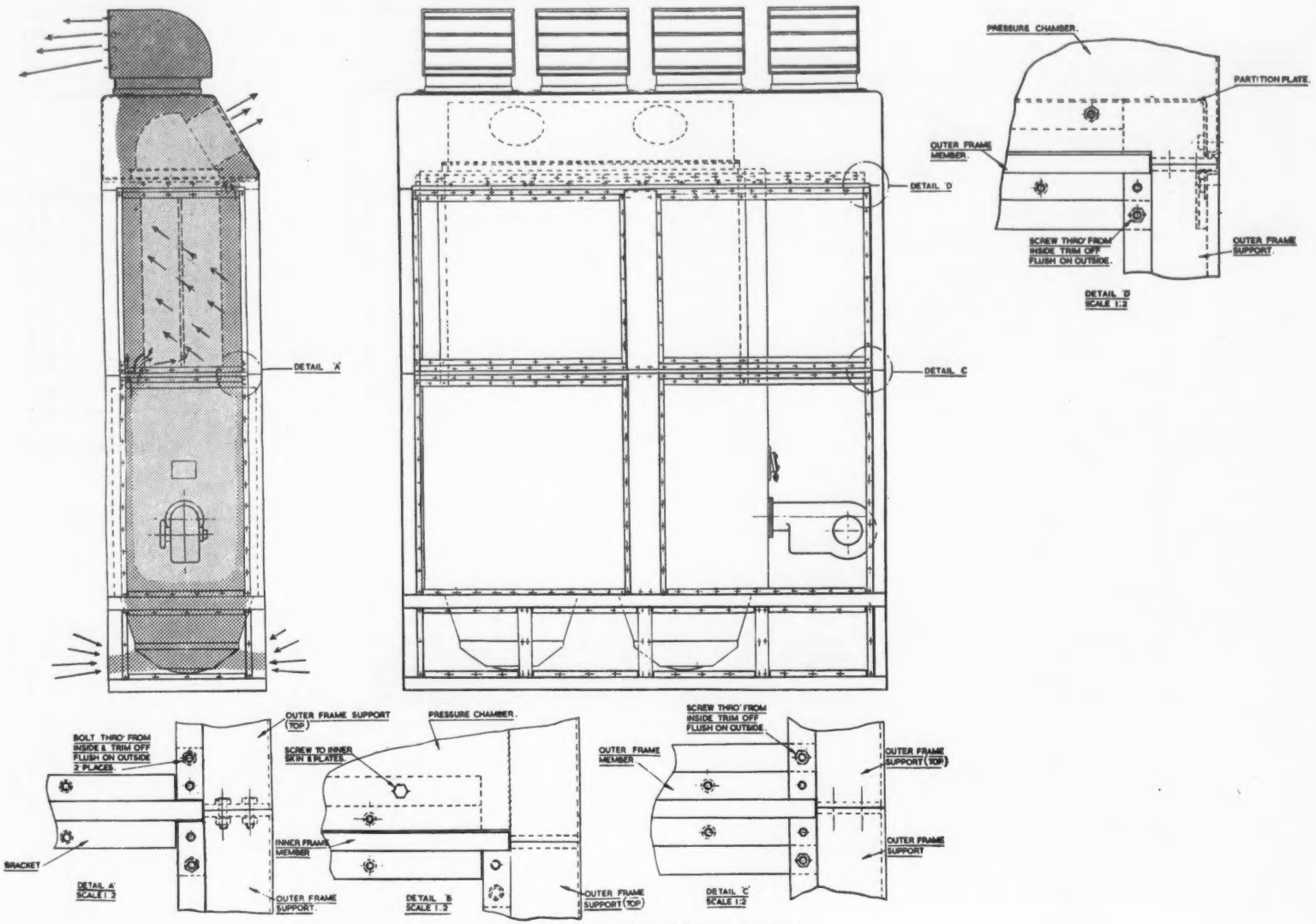

DETAIL 'A'
DETAIL 'C'
DETAIL 'D'
PRESSURE CHAMBER.
PARTITION PLATE.
OUTER FRAME MEMBER.
SCREW THRO' FROM INSIDE TRIM OFF FLUSH ON OUTSIDE.
OUTER FRAME SUPPORT.
DETAIL 'D' SCALE 1:2
BOLT THRO' FROM INSIDE & TRIM OFF FLUSH ON OUTSIDE 2 PLACES.
OUTER FRAME SUPPORT (TOP)
SCREW TO INNER SKIN & PLATES.
INNER FRAME MEMBER.
BRACKET
DETAIL 'A' SCALE 1:2
OUTER FRAME SUPPORT.
DETAIL 'B' SCALE 1:2
OUTER FRAME SUPPORT (TOP)
SCREW THRO' FROM INSIDE TRIM OFF FLUSH ON OUTSIDE.
OUTER FRAME MEMBER
OUTER FRAME SUPPORT (TOP)
OUTER FRAME SUPPORT
DETAIL 'C' SCALE 1:2

Fig. 6. Sub-assembly of heater structure.

hangars and, coupled with the floor heating, a number of unit heaters of high duty have been employed by the large doors. The results have been particularly successful in such types of buildings because the factory employees have enjoyed a greater sense of comfort, even allowing for the intermittent opening of the doors — often in the face of prevailing winds. This is due to the fact that although there has been an appreciable fall in temperature when the doors are opened, the factory operative is still subjected to the low temperature radiation from the warm floors.

More recently there has been installed in certain factories a system of floor heating using electric elements embedded in concrete floor slabs. This installation operates on the principle of using electricity during "off peak" hours when it can be obtained at a much cheaper rate. In my view, it can reasonably be said that there is a very limited application for floor heating because, in general, it is not possible to provide sufficient heat "input" in the floor areas. By this I mean that the factor which determines the practicability is the difference between floor surface temperature and factory air temperature, as it is upon this that the quantity of heat output from the floor depends. The floor surface temperature must, for reasons of human comfort, be limited to approximately 75°F and if the factory air temperature is 60°F, it only allows a difference between the two of about 15°F. In these circumstances, as I have said before, the required heat input — with consequent heat output — cannot generally be obtained.

automatic controls

The foregoing deals with the review of methods of factory heating, but before dealing with factory ventilation, I want to refer to the question of automatic controls for heating installations. Earlier in this review I stressed the importance of insulating factory roofs, because of the resultant fuel saving and the improvement achieved in comfort conditions. The installation of automatic controls to the heating installation can similarly bring about considerable saving in fuel and maintenance of comfort conditions. Let us quickly examine the benefits of automatic controls. The basic design condition of a factory heating installation is upon an external temperature of 30°F, and under this external temperature maintaining the required temperature inside the factory of, say, 60°F. The difference between external design temperature and inside factory temperature is therefore 30°F. The average outside temperature in England, during the winter months, however, is 43°F, making a difference between this average outside temperature and the factory temperature of 17°F, instead of 30°F upon which the installation is designed. This means that when the outside temperature is around the average of 43°F approximately only one-half of the heat input to the factory is required, and as the outside temperature continues to rise, a progressively smaller heat input is required. Unless steps can be taken by some means of automatic control to reduce the heat input to the factory during those times when the external temperature is above the external design figure of 30°F, very severe wastage of fuel will be taking place. There are widely different ways of applying automatic controls to a heating installation and the design of the automatic controls must be in accordance with the particular form of heating provided. No new installations should be provided without automatic controls, and heating installations of existing factories should be examined to see what can be done to apply some form of automatic control. The initial cost of automatic controls need represent only a small percentage increase in capital costs, and it can safely be said that it will take a period of a few years to write off this extra cost in fuel saving. In addition to the saving of fuel which can be obtained by the use of automatic controls, there is the further question of increased efficiency that can be obtained from the factory operatives by maintaining a steady comfortable condition within the works. Factory executives seem to be quick to appreciate the loss of production that arises when the factory is cold but, unfortunately, they appear to be slow in realising that a factory which is too warm can also lower the efficiency of their employees. This is particularly noticeable in those factories where the work is not mechanised and is of a repetitive nature, when output can fall due to a sense of lassitude amongst the workers.

At the beginning of this Paper, I cited the requirements of the Factories Act and in respect of ventilation, with which I will now deal, it must be stated that the Factories Acts are of a limited nature, except in regard to the requirements for the removal of odours or fumes which may be detrimental to the health of the employees. There is not space here to deal with the various special plants necessary for the removal of odours and fumes and we must, therefore, confine ourselves to questions of general ventilation and the equipment that may be used.

Rates of ventilating spaces of any kind are standardised in the form of air changes per hour and the number of air changes per hour is a function of the volume of air in cubic feet per hour introduced into the space to be ventilated, divided by the cubic capacity of the spaces. Thus, if 3,000,000 cu. ft. per hour of air are introduced into the space which has a cubic capacity of 1,000,000 cu. ft., then an air change of three times per hour is obtained.

Ventilation can be by natural or mechanical means. In the former case, its rate must depend upon the natural forces of the wind, and the temperature difference between the space to be ventilated and the outside air. As it is not possible to control either the velocity or the direction of the wind, or the external temperature, it follows that equally it is not possible to obtain any predetermined rate of air change when natural ventilation is employed.

Most factories of an appreciable size are of the single storey type and quite often rely upon windows in the external walls and natural ventilators in the ridges of the roofs to obtain the required degree of ventilation. During cold days it is generally impracticable to open the windows to any extent,

because of the draughts that would arise and, therefore, more often ventilation is obtained by the natural roof ridge ventilators. During times of low external temperature and high winds these roof ventilators can operate quite efficiently, but so often they are responsible for rates of ventilation quite beyond that which is necessary for reasonable standards of comfort within the factory. In these circumstances, once again fuel is being severely wasted. In periods of hot weather, coupled with still, sultry days, these natural ventilators are less effective than in the winter time and because of these reasons, it is perhaps surprising to see how extensively they are employed. Is it because when a factory is built it appears to the person responsible for the building that they are a "must" in the same way as the floor or roof ? The behaviour of such ventilators in both summer and winter conditions does not appear to be considered in detail.

mechanical ventilation

If ventilation is to be achieved on a positive basis, then it must be by mechanical means. Mechanical ventilation can take one of three forms — the first is by discharging into the space to be ventilated known quantities of air by means of fans and allowing the air to escape to outside atmosphere by natural means. The second is by extracting from the space, by means of fans, known quantities of air and allowing the air which is to make up that which is being exhausted to enter the factory by natural means, such as through doors and windows. The third is to have fans for both supplying and extracting air.

So often one sees means of extracting air from factories employed without any thought as to how the air to make up that being extracted is going to enter the premises, with resultant complaints in the winter time that cold draughts exist. This, of course, can only be expected when the air entering the factory, to make up for that which is being extracted, is unheated outside air coming in through doors, windows, etc. It is important, therefore, to appreciate that if a factory demands mechanical extract ventilation on any scale, then satisfactory results will seldom be obtained unless mechanical inlet ventilation is also provided, and with the mechanical air supply plant additional means provided for tempering the air to prevent complaints of cold draughts arising.

There are factories where the production processes demand extract ventilation on appreciable scales and having, I hope, now accepted the principles which demand an inlet supply plant also being provided, we might examine the equipment required for such plants and how they can be applied under varying circumstances.

extraction plant

The extraction plant consists fundamentally of one or a number of extraction fans, generally connected to a system of extraction ductwork, with extraction grilles or hoods at the strategic points where concentrated extraction is required.

The supply plant, which is to deliver air to the factory to make up for that which is being extracted, is similar to the extraction plant, insofar as the fan and ductwork is concerned, but in addition will have some form of heater battery to temper the air, together with air filtration equipment, and perhaps an air washer plant. There are very many types of air filters, some good and some bad, and I propose to examine some of the types available. In considering the various types we must relate the condition of the atmosphere to be filtered to the degree of filtration required, coupled with the capital and maintenance costs of meeting these requirements. The most effective filter, of course, is one that will arrest the largest quantities of all particles of dust, irrespective of the size of the particles. Therefore, if one is told that a filter is 99.9% efficient what does this mean ? In actual fact, absolutely nothing, because the 99.9% efficiency must be related to the size of the dust particle — by this I mean that a chicken wire screen would be 99.9% effective in removing particles the size of tennis balls, but it would hardly be considered effective as an air filter. Quite recently a British Standard Specification has been issued defining the methods of determining the efficiency of air filters, but, unfortunately, manufacturers generally, at present, are not using the specification. Therefore, until such time as air filters are sold on the basis of this B.S. Specification, it will be necessary to rely upon the advice and integrity of the ventilating engineer designing the plant, as he should not have any bias for or against any particular make.

types of filters

Filters may broadly be divided into two groups. Firstly, the renewable type and, secondly, the cleanable type without the necessity for renewal. Obviously the cleanable type is the less costly, insofar as maintenance is concerned — providing the cleaning is a simple operation and that when the filter has been cleaned its efficiency can be restored to approximately its original condition.

The renewable types consist of units having elements such as glass silk, paper, cotton wool, etc., are quite cheap in initial cost, but over a period of years the costs of continually replacing the elements on a plant of any appreciable size can be quite expensive. The filtering efficiency of glass silk and cotton wool elements is quite good and suitable for most industrial applications. Of the cleanable types there are two main kinds. The first consists of an element containing a zig-zag set of metal plates, which are coated with a solution of an adhesive nature, so that the airflow over the zig-zag plates deposits the dust on the coated surfaces. The cleaning of the filters is done by means of soaking the filters in a bath containing a special solution which removes the dirt and the adhesive solution from the plates, after which the elements can be re-impregnated ready for use. This cleaning operation is a very unpleasant job, and often not too successful, with the result that some users of these filters find the only satisfactory

way to restore them to their original condition is by boiling them in a strong solution of caustic soda. Owing to the objections in cleaning this type of filter, it is also possible to obtain what are known as "self-cleaning oil filters". These, however, are quite expensive in initial capital cost, and whether they are of the self-cleaning type or not, they are in my view not so efficient as some of the dry fabric type to which I have previously referred.

A more recent type of cleanable filter that is available is the multi-brush type, which consists of a series of brushes on wire formers, so that the air streams past through a dense mat of brushes. These brushes, which are similar to bottle brushes on a larger scale, are easily cleaned by means of a vacuum cleaner, and their maintenance costs are almost negligible because the brushes have a long life. Their filtering capacity is, I believe, slightly lower than the glass silk types and they are used extensively for industrial purposes with very satisfactory results.

Finally, on the subject of filters, I would refer to the electrostatic type. These are the most expensive and are, in fact, so costly that they are seldom used, except where the standard of filtration required is so high that the more usual types are not acceptable. The principles of such filters are based upon the creation of an intense electrostatic field between fine charged wires and earthed rods through which the air particles are passed, and then through a series of earthed plates where the dirt particles adhere until removed by the routine washing operation.

It will be noted that I have dealt at some length with the question of air filtration, but only because it forms such an important part of any ventilating system where quantities of air are drawn from outside and discharged into the space to be ventilated. I firmly believe that the high degree of dust content in the air which we breathe daily is seldom appreciated and an inspection of the air filters removed from a ventilating plant would, undoubtedly, shock most people. Because of this, it is essential to appreciate that ventilating engineers do not recommend filters either on a theoretical basis or to increase the cost of the equipment which they are selling.

"air washers"

Before leaving the subject of air filters, I want to refer to what are commonly termed "air washers". The name is really a misnomer, because as washers or cleaners of air they are far from effective. An air washer consists of a chamber through which the air is passed and in this chamber there is a number of high pressure water spray nozzles creating a blanket of atomised water. Having passed through the spray chamber, the air then passes through a series of baffle plates, known as eliminator or scrubbing plates, with the object of depositing any water contained in the air before it is discharged into the ventilating system. The prime function of an air washer — and a better name — is an air humidifier and, as such, it is extremely satisfactory.

"air conditioning"

It may have been noted that, so far, I have refrained from using the term "air conditioning" whilst dealing with the subject of air movement. This term air conditioning is a most abused term used by many people when referring to anything with which a fan is associated. I hope that after this Paper there will not be any members of The Institution of Production Engineers referring to "air conditioning" when in actual fact they do not mean it.

Let us, therefore, clearly define and appreciate the term "air conditioning". It means the treatment of air with the object of controlling both its temperature and humidity to within predetermined levels. To clarify this still further, we will examine the physical condition of air under varying changes of temperature and humidity. A particular sample of air is measured in respect of what is known as its dry bulb and wet bulb condition. The dry bulb condition is the one read from a normal thermometer and the wet bulb condition by means of a second thermometer similar to that used for dry bulb readings, except that the mercury bulb is encased in a muslin sheath, the end of which is submerged in a small bottle of water. The condition of the air surrounding the saturated muslin sheath will determine the temperature that will be read off the wet bulb thermometer. Thus, if the humidity of the space from which the sample is being taken is below 100%, then the surrounding air will be able to absorb and evaporate moisture from the sheath and in doing so will cool the wet bulb thermometer. The drier the air being sampled, the greater the depression that will occur on the wet bulb thermometer, indicating a lower humidity. Conversely, the wetter the atmosphere the less moisture will be absorbed, resulting in readings on the dry and wet bulb thermometers being closer together. From the readings of these two thermometers it is easy to plot the relative humidity of the samples on a graph known as a Psychrometric Chart.

On a drizzling, rainy day, the air is almost saturated and, as such, the humidity is 100%, that is to say, it has absorbed the maximum amount possible of water vapour. Again, on a hot, humid day, when the humidity is stated to be 75%, it means that the air contains 75% of the moisture that it is capable of absorbing under that particular temperature condition before becoming saturated. Thus dry bulb temperatures are expressed in degrees Fahrenheit and humidity in a percentage at that particular temperature. I emphasise "a particular temperature condition" because, if air at a certain dry bulb temperature and percentage of relative humidity is raised in temperature, then the percentage relative humidity will fall as the air will contain the same amount of moisture, but because it is at a higher temperature it will be able to contain a greater quantity of moisture before it is saturated. Explaining this simply, it means that raising the temperature of air at a particular condition will lower its humidity and lowering its temperature will increase its humidity.

In an ordinary ventilating plant, consisting of a fan filter and heater battery, it is possible in the winter to raise the temperature of the air only and in the summer no control at all is possible, which means that the air which is delivered to the ventilated space must be in a similar condition to that prevailing outside the building. It is plants of this nature that are commonly referred to as air conditioning installations which, of course, is quite incorrect.

Let us consider what additional plant is required to provide full air conditioning and what it means in terms of capital expenditure and running costs. At the same time we will assume that it is desired to maintain a condition of 70°F and 55% relative humidity all the year round, irrespective of the outside weather conditions.

In the winter it will obviously be necessary to warm the air if a temperature of 70°F is required inside the building. I mentioned earlier that in raising the temperature of the air the humidity would be lowered ; therefore, additional plant is required in the winter to correct the humidity and this takes the form of a conditioner which, in fact, is an air washer, to which I have referred previously. The air is passed through the spray chamber of the air washer and in doing so, it picks up the required amount of moisture to obtain the predetermined degree of humidity. The correction of temperature and humidity conditions in the winter is the simple and least costly side of the conditioning operation and it is when dealing with the summer conditions that the high costs arise. This is because refrigeration plant is necessary to remove the heat and lower the temperature of the space being conditioned. To maintain in the summer a condition at a lower degree than that prevailing outside means the removal of heat from the outside air and, in addition, the heat from such items as machines, human beings and the sun effect on the walls, roof, etc., of the building.

A plant that would cost approximately £10,000 for ordinary ventilation, would cost at least double if full air conditioning was required and, in addition, would necessitate additional high running costs due to the substantial size of the motors required for the refrigerating compressors, and so on.

Having briefly explained what is involved when air conditioning is employed, it may perhaps be asked — "But what factory needs such equipment ?". Although for ordinary factory buildings in this country air conditioning, as far as I am aware, is never employed, there are very many production processes where, without full air conditioning, it would be impracticable to maintain production. Some of the largest users of full air conditioning equipment are in the chemical and pharmaceutical industries, where extremely exacting conditions have to be maintained, otherwise their products would be spoiled. In addition, there are many industries where pilot plants are necessary for experimental purposes and for these experiments to be of any use, it is absolutely essential to maintain accurate control of temperature and humidity.

It will be appreciated that in this brief review it has not been possible to deal in great detail with some of the aspects of what is a very wide field, but I hope sufficient has been said to focus more attention on this very important subject.

acknowledgments

Acknowledgments are due to Mr. R. E. Chittock for his assistance in preparing Figs. 1, 2 and 3 ; Messrs. Troughton & Young (Heating) Ltd. for their permission to use Fig. 4 ; and Messrs. Flexaire Ltd. for Figs. 5 and 6.

PERA QUARTERLY NEWSLETTER—continued

"Specification and Grinding of Cutting Tools" by J. K. Church and D. A. Wight.
"Recent Developments in Drilling and Tapping" by R. J. Cowie and J. O. M. Pegler.

Copies of Papers can be purchased from the Secretary, The Institution of Mechanical Engineers, 1 Birdcage Walk, London, S.W.1.

The programme for the Conference was drawn up over a period of about two years by a planning panel under the Chairmanship of Dr. Galloway, Director of PERA.

Russian visitors to PERA

Professor N. N. Zorev, Professor V. V. Boitsov, and Mr. G. N. Krasnitsky, of the U.S.S.R., recently visited PERA during the course of a 10-day visit to Britain to study developments in the technology of engineering, manufacturing, etc. Professor Zorev is head of the Russian Central Scientific Research Institute for Technology and Heavy Machine Building, which has a staff of approximately 4,000 engaged in the design, development and manufacture of prototype machines, etc., for Russian industry. Professor Boitsov is a welding expert on Professor Zorev's staff, and Mr. Krasnitsky is technical director of a machine tool firm. During their visit to PERA the Russian scientists described some interesting Russian developments in production techniques. As a result of negotiations which are at present taking place, the Association is hoping to receive periodical reports on technical and scientific developments on many different aspects of manufacture from official Russian sources.

Production Engineering Research Association of Great Britain

Quarterly Newsletter to the Institution

membership

The recent sharp increase in the rate of growth of the Association continued during the first three months of the year, and the total membership is now over 650 firms manufacturing every important type of consumer goods and capital equipment in quantities ranging from one-off to mass production. The knowledge and experience built up at PERA over the past 12 years have been shown to be directly applicable over a larger area of the manufacturing industry than is immediately apparent, with the result that companies not exclusively concerned with engineering are now deriving substantial benefits from membership of the Association. It has been possible to assist these firms by carrying out efficiency surveys, investigating mechanical handling, improving works layout and packaging methods, reducing material consumption, designing special purpose equipment, etc.

automation

As nearly all firms, both large and small, will ultimately be directly affected by the many developments that are now taking place in automation, PERA has been carrying out an operational research into a wide range of automation equipment to assist members in applying these devices. A report entitled "Guide to Work Handling Equipment for Machine Tools and Presses, Part 1 — Hoppers and Selector Devices" was recently issued to members. Subsequent reports will cover work loading and unloading equipment such as magazines, mechanical hands, iron hands, etc.; work clamping equipment; work conveying equipment; the application of various types of automation equipment in machining and press-working in small and large quantity production, and transfer machine tools and presses.

education and training

An extensive programme of five-day courses has been arranged for this year and reservations are now being made. Nominations from PERA member firms can still be accepted for the following courses :-

1st September, 8th September, 15th September
Presswork and Metal Forming.

22nd September, 29th September, 6th October
Improved Production Techniques.

13th October, 20th October, 27th October
Metal Cutting.

10th November, 17th November, 24th November
Improved Production Techniques.

T.E.M. Conference

At the recent Conference on the Technology of Engineering Manufacture arranged by The Institution of Mechanical Engineers, five of the Papers presented dealt with research and development carried out by PERA. These Papers were as follows :-

"Some Experiments on the Impact Extrusion of Aluminium, Copper and Steel" by Dr. D. F. Galloway.

"Blanking and Piercing" by R. Tilsley and F. Howard.

"The Thread Rolling Process" by D. H. Seymour and F. M. Lomas.

(concluded on facing page)

Dr. D. F. Galloway (second from right), **Director of PERA, discussing vibration research with Professor N. N. Zorev** (right), **Head of Russia's Central Scientific Research Institute for Technology and Heavy Machine Building, Mr. G. N. Krasnitsky** (left) **and Professor V. V. Boitsov** (second from left) **in the Association's laboratories. The Russian party were visiting PERA during the course of a stay of about 10 days in Britain to study developments in the technology of engineering manufacture, etc.**

institution notes

MIDLANDS REGION CONFERENCE

"Machining — Tomorrow's Production" . . . this was the theme of the Annual One-day Conference organised by the Midlands Region of the Institution, and held at the works of Cincinnati Milling Machines Ltd.

The President, The Rt. Hon. The Earl of Halsbury, spoke of the coming of the "Electro-mechanical Revolution" and in his Address strongly recommended syndication between the mechanical engineer and the electrical engineer, associations such as exist in the atomic energy field, where the specialist skills are represented by independent firms, to all those interested in the future of the machine tool industry.

The President of the Institution, Lord Halsbury (left), with Mr. B. G. L. Jackman, Midlands Region Chairman, chats with Mr. H. H. Evans, M.I.Prod.E., a Director of Hordern, Mason & Edwards Ltd., and Mr. J. A. Beebe, U.S.A. Managing Director of Cincinnati Milling Machines Ltd., at the Conference.

The President's Address was followed by three most interesting Papers: "Machining the Unmachinable", read by A. R. Hambridge, which described some of the cutting tool research carried out by Cincinnati, using such advanced techniques as radio active isotopes, electro-erosion and hot machining; "Chipless Machining", presented by A. G. Cochrane and A. Powell-Tuck, which dealt with hydroforming and hydrospinning metal forming developments in the United States; and "Numerical Control of Machine Tools" by O. S. Puckle, which enabled the delegates to appreciate the merits of digital and analogue controls when applied to tape controlled machines.

During the afternoon the delegates were able to tour the adjoining manufacturing plant and to see many examples of the latest developments in machine tools, including a demonstration of a three-dimensional tape controlled milling machine.

The Regional Committee is pleased to note the support it is receiving from members for this Annual One-day Conference and will continue to arrange these very intensive and informative functions.

The Midlands Region is indebted to the Directors and Staff of Cincinnati Milling Machines Ltd. for their hospitality in receiving this Conference and their sustained enthusiasm in putting the complete factory at the disposal of the delegates.

BIRTHDAY HONOURS

The Institution offers congratulations to the following members who have been honoured by H.M. The Queen:

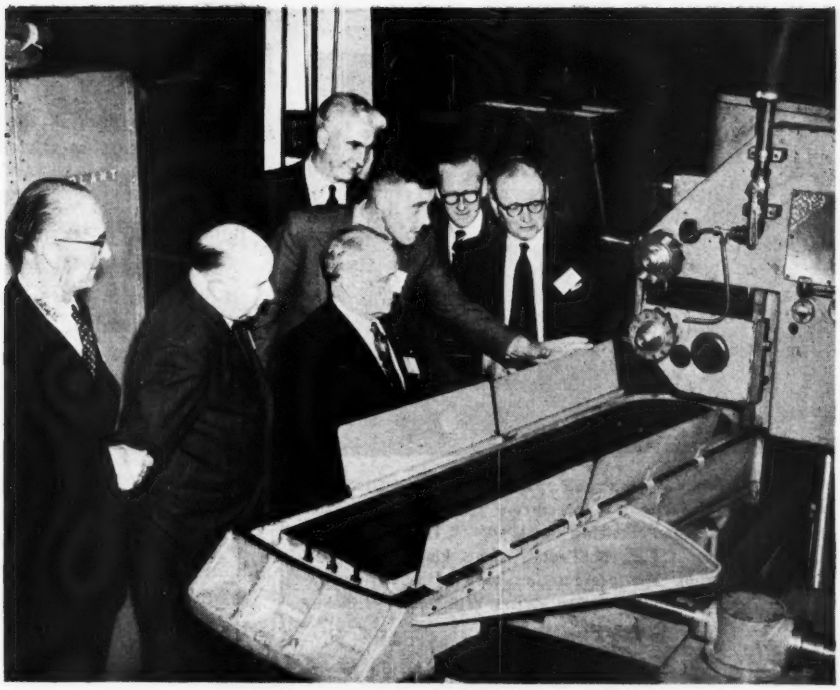
O.B.E.

Mr. R. W. Mann, Member, for his services as Chairman of the Tyneside Productivity Committee.

Mr. G. Murray, Member, Production Controller, Engineering Group, Remploy Ltd.

M.B.E.

Mr. W. H. Hodgetts, Member, Production Manager, Copper Products Group of Imperial Chemical Industries Ltd.



MIDLANDS REGION CONFERENCE — a party of delegates during the works tour.

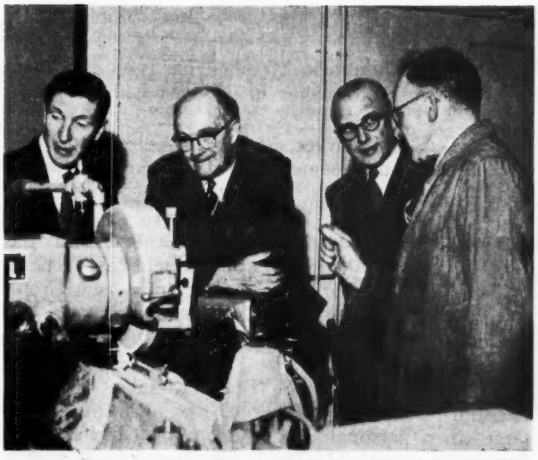
PRESIDENTIAL VISIT TO THE UNIVERSITY OF BIRMINGHAM

On 7th May, The Right Hon. The Earl of Halsbury, President of the Institution. paid an official visit to the postgraduate Department of Engineering Production in the University of Birmingham and to the Department's residential Institute for Engineering Production.

Lord Halsbury was received at the Institute by Dr. R. S. Aitken, Vice-Chancellor of the University; Dr. N. A. Dudley, Head of Department; and members of the University Senate and Council. Dr. T. U. Matthew, former Head of Department, and Mr. R. N. Marland, Chairman of the Birmingham Section of the Institution, were also present.

After lunch, Lord Halsbury toured the Department where he discussed current research work on machine tools, work measurement and operational research, and addressed members of staff and of the M.Sc. and Diploma Course in Engineering Production. Thanking Lord Halsbury for his visit, Dr. Dudley expressed the view that his support would do much to encourage and foster production engineering activities not only at Birmingham, but also in other Universities.

Later, Lord Halsbury attended his first meeting as a member of the Institute's Advisory Committee, where it was reported that during the past five years nearly 2,000 senior production engineers and industrial executives had attended short residential courses on operational research, work study, production planning and control and associated subjects.



(Left to right) **Dr. N. A. Dudley, Lord Halsbury, Mr. R. N. Marland and Mr. H. Grisbrook discussing research on the factors affecting efficiency in precision grinding.**

NEW CHAIRMAN FOR TEES-SIDE

Mr. J. W. Woodger, M.I.Prod.E., has been elected Chairman of the Tees-Side Section for the current year. This photograph shows Mr. Woodger receiving the Chain of Office from Mr. B. A. Williams, C.B.E., M.I.Prod.E., who kindly presented it to the Section. The presentation took place during the first works visit of the Section to Messrs. Williams & Williams, Chester, last May.

OBITUARY

Mr. E. G. Eaton, Member, who died suddenly while on holiday. Mr. Eaton was, at the time of his death, a member of the Preston Section Committee, having already served as Chairman of the Section, and as a member of the North West Regional Committee. He was Works Director of Howard & Bullough Ltd., Accrington, Lancashire.

Mr. Eaton was always wholehearted and enthusiastic in his support of the activities of the Institution, and did much sterling work in the North Western area, where his loss will be particularly keenly felt.

Mr. E. E. Martin, Associate Member, Works Manager of Alfred Wiseman & Co. Ltd., Bordesley, who was killed when part of a wall collapsed outside his works. Mr. Martin was a member of the Birmingham Section of the Institution, and his untimely death was a great shock to his many friends and colleagues.

news of members

Mr. S. J. Burrage, Member, has been appointed a Director of J. Parkinson & Son (Shipley) Ltd.

Mr. W. J. Dimmock, Member, has been appointed General Works Manager of Hoover Ltd., Perivale.

Mr. T. E. H. Gwyer, Member, has recently been appointed Factory Manager of The Brantford Coach and Body Ltd., Ontario, Canada.

Mr. E. W. Hancock, O.B.E., Past President, has recently relinquished his appointment as General Manager of Humber Ltd., to take up a new Group appointment as Director of Special Projects. Mr. Hancock remains on the Board of Humber Ltd.

Mr. W. S. Hollis, B.Sc.(Eng.), Member, Assistant Director, Ministry of Supply, has been invited to serve, in a personal capacity, on the Mechanics of Formation and Machine Shaping of Materials Committee which, under the Mechanical Engineering Research Laboratory Board, advises on the work to be undertaken at M.E.R.L., East Kilbride.

Mr. W. W. Jeacock, Member, has been appointed General Manager of Coventry Gauge & Tool Co. Ltd. Mr. Jeacock joined the Company in 1921, when he took up an apprenticeship, and was appointed Works Manager in 1951. He is a member of the Institution's Coventry Section Committee.

Mr. S. E. Willett, Member, who has, at the request of Clayton Dewandre Co. Ltd., served the Company beyond the normal retiring age, has decided not to renew his contract as Managing Director on its present expiry. The Board are pleased to announce that Mr. Willett will remain a member of the Board of the Company.

Mr. N. S. Fowler, Associate Member, has moved to the Bath district to represent the Belliss and Morcam Group in the South West of England.

Mr. E. Hampshire, Associate Member, formerly Technical Superintendent, Spring Manufacture, of Samuel Fox & Co. Ltd., a subsidiary of The United Steel Companies Ltd., has been appointed Production Controller.

Mr. J. Hunter, Associate Member, has relinquished his position of Production Engineer with Blackburn (Dumbarton) Ltd., and is now Production Engineer with R. & A. Main Ltd., Gothic Works, Falkirk.

Mr. V. Lee-Brown, Associate Member, is now a Mechanical Engineer with Nash & Thompson Ltd., Instrument Makers, in the Thorn Electrical Industries Group.

Mr. J. W. Oddey, Associate Member, has relinquished his position with the Lancashire Dynamo & Crypto Ltd., to take up an appointment with Production Engineering Ltd., London.

Mr. K. Staple, Associate Member, has been appointed Lecturer in Production Engineering at the Bournemouth Municipal College.

Mr. D. J. Taysom, Associate Member, a Director of Cimex-Fraser Tuson Ltd., has been appointed General Manager.

Mr. A. C. S. Ensell, Graduate, has relinquished his position as a Manufacturing Engineer with the Industrial Gas Turbine Division of the Westinghouse Corporation in Philadelphia, U.S.A., and has returned to Dominion Engineering Co., of Lachine, Montreal, as Research Engineer, Market and Product Planning in the Diesel Division.

Mr. J. C. Holst, Graduate, has been transferred from Philips Electrical Ltd., Eindhoven, Holland, to Philips' Croydon Works, Croydon, in the Production Engineering Department.

Mr. A. M. Nisbet, Graduate, has now joined Personnel Administration Ltd., as a long-term trainee industrial management consultant.

Mr. C. R. Southern, Graduate, has taken up a position as a machine tool representative with Charles Churchill & Co. Ltd.

Mr. A. G. Diggle, Graduate, has resigned his position with The English Electric Co. Ltd., to take up an appointment with the I.C.I. Lime Division.

Hazleton Memorial Library

ADDITIONS

Aslib, London. **"Aslib Directory": a guide to sources of information in Great Britain and Ireland.** Edited by Miriam Alman. *London, Aslib,* 1957. 2 *volumes,* 179, 1,018 *pages.* £5 5s. 0d.

Lists 3,303 libraries and other organisations capable of supplying specialised information, indicates their scope, and to whom they will supply information. Volume 1 comprises the explanatory notes, an index classified by subject, alphabetical subject, and name indices, and notes on library co-operation, and on union lists and catalogues. Volume 2 contains the full entries divided geographically by town, and a regional index divided by county.

Barnes, Ralph M. **"Work Sampling."** 2nd edition. *New York, Wiley; London, Chapman and Hall,* 1957. 283 *pages. Diagrams.*

In this book the author gives an account of the fundamental techniques used in work sampling, and gives specific directions on how to use them in specific circumstances. It includes a report of an investigation undertaken by the author and Robert B. Andrews at the University of California on performance sampling. The book includes an extensive bibliography and a table of random numbers.

Barnes, Ralph M. **"Motion and Time Study."** 4th edition. *New York, Wiley; London, Chapman and Hall,* 1958. 665 *pages. Illustrated. Diagrams.* £3 14s. 0d.

"The main purpose of this revision of *Motion and Time Study* has been to present new material in the area of motion and time study and to include more and diverse illustrations. In this edition the author has adhered to his original purpose of presenting the basic principles that underlie the successful application of motion and time study, supplementing each with illustrations and practical examples. Five new chapters have been added, dealing with motion study; mechanisation and automation; mechanised time study and electronic data processing; systems of motion-time data; work sampling; evaluating and controlling factors other than labour; and multi-factor wage incentive plans."

Belchem, R. K. F. **"A Guide to Nuclear Energy."** *London, Pitman,* 1958. 77 *pages. Diagrams.* 10s.

This book attempts to explain to persons without specialised knowledge the theory of nuclear reaction and the manner in which nuclear power reactors function. Only an elementary knowledge of physics is necessary for its comprehension.

Benson, F. A. **"Problems in Electronics with Solutions."** *London, Spon,* 1958. 219 *pages. Diagrams.* 36s.

The author is Lecturer in Electrical Engineering at the University of Sheffield. Although the book has not been compiled to match any particular syllabus, an attempt has been made to cover almost the complete undergraduate electronics course at the universities, and there are also a few problems of post-graduate standard. There are 282 problems divided into 23 sections, with the solutions separated from the problems. The answer is also given at the end of each problem for convenience.

Bowman, Edward H.; and Fetter, Robert B. **"Analysis for Production Management."** *Illinois, Richard D. Irwin,* 1957. 503 *pages. Diagrams.*

An advanced text book of production management from the viewpoint of the analysis of the economic problems involved. The book presupposes a knowledge of mathematics at university level, and of the basic principles of calculus, statistics and economics. The chapters are arranged in groups potentially useful for methods analysis in making economic decisions. Contents: Section 1 — Orientation. Section 2 — Mathematical programming. Section 3 — Statistical analysis. Section 4 — Economic analysis. Appendix — Case studies.

British Iron and Steel Research Association, London. **"Annual Report, 1957."** *London, the Association,* 1958. 143 *pages. Illustrated.*

Buckingham, Earle. **"Analytical Mechanics of Gears."** *New York, London, etc., McGraw-Hill,* 1949. 546 *pages. Diagrams.* 93s.

"Among the machine elements that have received much less analytical attention than they deserve are linkages, cams and gears. The book attempts to give in usable form such a general analysis of gears . . . This is not a text on gear design. The major effort had been to make apparent the nature of the action and contact between the contacting teeth of the different types of gears. A clear understanding of these features is essential if the designs are to exploit the full possibilities of these mechanical elements."

Burnham, T. H., and Hoskins, G. O. **"Elements of Industrial Organisation." (Engineering Economics: Book 1.)** Sixth edition. *London, Pitman,* 1958. 330 *pages.* 21s.

The first edition of "Engineering Economics" was published in 1929, primarily in order to help students who were preparing for The Institution of Mechanical Engineers examination in engineering economics, which had been instituted in 1924. Its author — T. H. Burnham — was one of the pioneers of management production in this country. He died in 1924, and so the latest editions of his book have been revised by other authors. The seventh edition of Book 2, "Factory Organisation and Management", revised by D. H. Bramley was published in 1957. The sixth edition of Book 1 is revised by G. O. Hoskins. It deals with the economic bases and fundamental techniques of industrial organisation, and should form an introduction to the reading required for the management subjects in the examinations of various professional institutions. Contents: Elements of economics — Money banking and exchange — Commonwealth and world resources — Industrial evolution — Business organisation — The Trade cycle — Control: statistics and charts — Elements of commercial law — Industrial legislation — Industrial relationships — Research and development work — Organisation and distribution — Office administration — The management function — Taxation and national income — Insurance — The State and industry.

Davies, H. **"Belt Conveyors."** Richmond, Surrey, Association of Engineering and Shipbuilding Draughtsmen, Session 1953 - 1954. *Richmond, the Association,* 1954. 181 *pages. Illustrated. Diagrams. Tables.* 6s.

A handbook on the design and functioning of all kinds of belt conveyors. Contents: Features — Uses — Conveyor belting — Belt fasteners — Idlers — Training the belt — Pulleys — Loading — Feeders — Carrying capacity — Speeds — Widths — Horse power to drive — Belt tensions, determination — Loads on pulleys — Tension take-ups — Angle of incline — Discharge — Anti-run back devices — Weighing — Shuttle conveyors — Portable conveyors — Separators — Drives — Drive arrangements — Starting and stopping — Typical galleries and housing — Typical constructional details — Typical belt conveyor arrangements — High life conveyors — Long conveyors — Typical examples of belt conveyor installations.

Fisher, E. G. **"Extrusion of Plastics."** *London, Iliffe for the Plastics Institute,* 1958. 114 *pages. Illustrated.* £1 1s. 0d.

One in the series of revised monographs issued by the Plastics Institute, which have been designed to cover the syllabus leading to the Diploma, Graduateship, and Associateship of the Institute. It is also useful as a comprehensive guide to the extrusion of plastics for the non-expert. The book covers briefly the phases of the processes from both practical and theoretical aspects. There are chapters on the basic principles of extrusion, the extrusion machines, the extrusion of thermoplastics and of thermosets, and a complete description of the extrusion process.

Glanvill, Alan B. **"Plastics Materials Handbook":** a concise reference of the principal plastics materials, giving their physical, mechanical and electrical properties, forms, colours, applications, decorations, cementing, etc. *Brighton, Machinery Publishing Company,* 1957. 67 pages. Diagrams. (Machinery's Yellow Back Series, No. 40.)

Contents: Thermoplastic materials — Thermosetting materials — Machining of plastics; manufacturing methods — Index of trade names.

Grabbe, Eugene M. (editor). **"Automation in Business and Industry."** *New York, Wiley; London, Chapman and Hall,* 1957. 611 *pages. Illustrated. Diagrams.* £4.

This book, by 21 authors, attempts to integrate the various techniques and sciences comprised by the word "automation". Contents: Introduction (historical developments, systems engineering, social implications, education, production and distribution) — Automation in business and industry — The language of automation — Fundamentals of automation (the roles of science, mathematics and engineering; design of an automatic system)— Feedback control systems — Basic concepts of instrumentation and control — Analogue computers — Digital computers — Data processing — Analogue to digital conversion units — Input/output equipment — Applications of electronic data-processing machines — Automatic control in flight — Automatic production of electronic equipment — Process control in the petroleum and chemical industries — Analogue computers in industrial control systems — Digital control of machine tools — Manufacturing automation (e.g. design of products and automatic assembly; economics of automation) — Economics of plant automation — The future of automation.

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Benson, F. A. **"Problems in Electronics with Solutions."** *London, Spon,* 1958. 219 *pages. Diagrams.* 36s.

The author is Lecturer in Electrical Engineering at the University of Sheffield. Although the book has not been compiled to match any particular syllabus, an attempt has been made to cover almost the complete undergraduate electronics course at the universities, and there are also a few problems of post-graduate standard. There are 282 problems divided into 23 sections, with the solutions separated from the problems. The answer is also given at the end of each problem for convenience.

Bowman, Edward H.; and Fetter, Robert B. **"Analysis for Production Management."** *Illinois, Richard D. Irwin,* 1957. 503 *pages. Diagrams.*

An advanced text book of production management from the viewpoint of the analysis of the economic problems involved. The book presupposes a knowledge of mathematics at university level, and of the basic principles of calculus, statistics and economics. The chapters are arranged in groups potentially useful for methods analysis in making economic decisions. Contents: Section 1 — Orientation. Section 2 — Mathematical programming. Section 3 — Statistical analysis. Section 4 — Economic analysis. Appendix — Case studies.

British Iron and Steel Research Association, London. **"Annual Report, 1957."** *London, the Association,* 1958. 143 *pages. Illustrated.*

Buckingham, Earle. **"Analytical Mechanics of Gears."** *New York, London, etc., McGraw-Hill,* 1949. 546 *pages. Diagrams.* 93s.

"Among the machine elements that have received much less analytical attention than they deserve are linkages, cams and gears. The book attempts to give in usable form such a general analysis of gears . . . This is not a text on gear design. The major effort had been to make apparent the nature of the action and contact between the contacting teeth of the different types of gears. A clear understanding of these features is essential if the designs are to exploit the full possibilities of these mechanical elements."

Burnham, T. H., and Hoskins, G. O. **"Elements of Industrial Organisation." (Engineering Economics: Book 1.)** Sixth edition. *London, Pitman,* 1958. 330 *pages.* 21s.

The first edition of "Engineering Economics" was published in 1929, primarily in order to help students who were preparing for The Institution of Mechanical Engineers examination in engineering economics, which had been instituted in 1924. Its author — T. H. Burnham — was one of the pioneers of management production in this country. He died in 1924, and so the latest editions of his book have been revised by other authors. The seventh edition of Book 2, "Factory Organisation and Management", revised by D. H. Bramley was published in 1957. The sixth edition of Book 1 is revised by G. O. Hoskins. It deals with the economic bases and fundamental techniques of industrial organisation, and should form an introduction to the reading required for the management subjects in the examinations of various professional institutions. Contents: Elements of economics — Money banking and exchange — Commonwealth and world resources — Industrial evolution — Business organisation — The Trade cycle — Control: statistics and charts — Elements of commercial law — Industrial legislation — Industrial relationships — Research and development work — Organisation and distribution — Office administration — The management function — Taxation and national income — Insurance — The State and industry.

Davies, H. **"Belt Conveyors."** Richmond, Surrey, Association of Engineering and Shipbuilding Draughtsmen, Session 1953 - 1954. *Richmond, the Association,* 1954. 181 *pages. Illustrated. Diagrams. Tables.* 6s.

A handbook on the design and functioning of all kinds of belt conveyors. Contents: Features — Uses — Conveyor belting — Belt fasteners — Idlers — Training the belt — Pulleys — Loading — Feeders — Carrying capacity — Speeds — Widths — Horse power to drive — Belt tensions, determination — Loads on pulleys — Tension take-ups — Angle of incline — Discharge — Anti-run back devices — Weighing — Shuttle conveyors — Portable conveyors — Separators — Drives — Drive arrangements — Starting and stopping — Typical galleries and housing — Typical constructional details — Typical belt conveyor arrangements — High life conveyors — Long conveyors — Typical examples of belt conveyor installations.

Fisher, E. G. **"Extrusion of Plastics."** *London, Iliffe for the Plastics Institute,* 1958. 114 *pages. Illustrated.* £1 1s. 0d.

One in the series of revised monographs issued by the Plastics Institute, which have been designed to cover the syllabus leading to the Diploma, Graduateship, and Associateship of the Institute. It is also useful as a comprehensive guide to the extrusion of plastics for the non-expert. The book covers briefly the phases of the processes from both practical and theoretical aspects. There are chapters on the basic principles of extrusion, the extrusion machines, the extrusion of thermoplastics and of thermosets, and a complete description of the extrusion process.

Glanvill, Alan B. **"Plastics Materials Handbook": a** concise reference of the principal plastics materials, giving their physical, mechanical and electrical properties, forms, colours, applications, decorations, cementing, etc. *Brighton, Machinery Publishing Company,* 1957. 67 pages. Diagrams. (Machinery's Yellow Back Series, No. 40.)

Contents: Thermoplastic materials — Thermosetting materials — Machining of plastics; manufacturing methods — Index of trade names.

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McLoskey, Joseph F., and Coppinger, John M. (editors). **"Operations Research for Management."** Volume 2. With an introduction by The Rt. Hon. The Earl of Halsbury. *Baltimore, Md., John Hopkins Press,* 1956. 563 *pages. Diagrams.* $8 (£3 3s. 0d.).

Volume 1 of "Operations Research for Management", published in 1954, provided an introduction to the history, principles, and methodology of the subject, and included some case histories. Volume 2 gives 13 more case histories; detailed discussions on new operational research methods; and a section on information handling in organised groups. Contents:

Introduction

From Plato to the linear programme (The Rt. Hon. The Earl of Halsbury).

Case histories

Operations analysis in the United States Air Force (Leroy A. Brothers) — Traffic delays in toll booths (Leslie C. Edie) — The influence of vehicular speed and spacing (Edward C. Olcott) — Road safety and traffic research in Great Britain (W. H. Glanville) — Revising New York's subway fare structure (William S. Vickery) — Ore handling at British ports (Roger T. Edison) — Analysis of a railroad classification yard (Roger R. Crane) — Queueing theory and cost concepts, applied to a problem of inventory control (Charles D. Fage)—Strip mining phosphate rock with large walking draglines (Jack W. Dunlap and Herbert H. Flage) — Operational research in the British coal industry (B. H. P. Rivett) — Operational research in underground mining (S. L. Cook) — Utilisation of training aircraft (Max Astrachan) — A study of combat stress in Korea: biosocial research in operations research (Stanley W. Davis).

Methods

Observation, experiment and measurement in operations research (W. H. Youden) — Operational organisation (David Bendel Hetyz and George J. Feeney) — Rounding the solutions of practical queueing problems by analytic methods (Glen D. Camp) — Failure of complex equipment (Gordon D. Shellard) — The travelling salesman problem (Merrill M. Flood) — Operational gaming in industry (Walter E. Cushen) — A Monte Carlo model for military analysis (Richard E. Zimmerman) — How is planning possible (C. West Churchman).

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Introduction (Lee S. Christie) — Organisation of information routing (Lee S. Christie) — Processes affected by noise and confusion of meanings (Josiah Macy, junior) — Some aspects of time and decisions (R. Duncan Lee) — Task types and requirements for organisation (Lee S. Christie) — Bibliography (Lee S. Christie).

Appendix

Bibliography of queueing theory.

McNeil, Ian. **"Trouble-free Hydraulics."** A practical handbook on maintenance and fault finding in oil hydraulic machinery. *London, Thames and Hudson,* 1958. 124 *pages. Diagrams. Charts. Tables.* 18s.

Written for the engineer, who, without a profound knowledge of hydraulics, uses hydraulic machinery and needs to know how to keep it running smoothly. Among the subjects dealt with are the laying down and carrying out of preventive maintenance schedules, starting up new machines, expected life of hydraulic oil, and diagnosis and cure of faults. Wherever possible maintenance and testing operations are described in chart form, and a series of charts presents common faults in hydraulic machinery, and lists possible causes and remedies. Contents: An introduction to the hydraulic system and the problem of systematic maintenance — Pipework and oil tanks — Hydraulic fluids and their treatment — Hydraulic seals and packings — The diagnosis and cure of faults — Appendix 1: Safe internal working pressure for cold drawn seamless steel tube (Table) — Appendix 2: Pressure, volume, work heat and power equivalents (Tables).

Redfarn, C. A. **"A Guide to Plastics."** *London, Iliffe; New York, Philosophical Library.* 2*nd edition.* 1958. 150 *pages. Illustrated.* 18s.

Contents: Plastics nomenclature — Raw materials for plastics — The manufacture of plastics materials — The fabrication of plastics — The properties of plastics materials.

Sharp, K. W. B. **"Practical Engineering Metrology."** *London, Pitman,* 1958. 249 *pages. Illustrated. Diagrams.* 30s.

Intended for students working for Higher National Certificates, City and Guilds examinations, and the Associate Membership examinations of The Institution of Mechanical Engineers and The Institution of Production Engineers. Questions of the standard applicable to these examinations are given at the end of each chapter. Contents: Apparatus and method — Measurement of length — Radius measurements — Straightness and flatness — Measurement of angles — Measurement of tapers — Screw threads — Machine tool testing — Surface texture — Miscellaneous measurements and the testing of measuring instruments — Design and manufacture of gauges and instruments — Tables — Bibliography — Selection of British Standard specifications.

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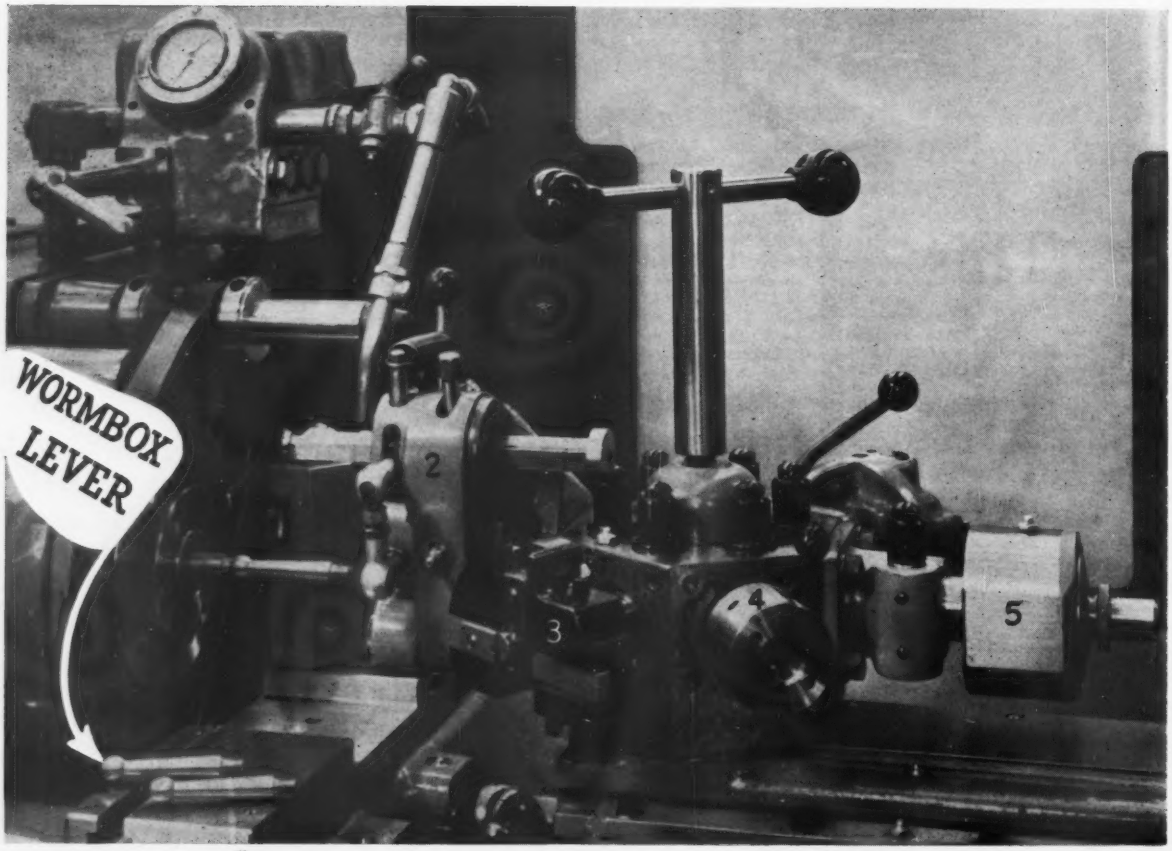

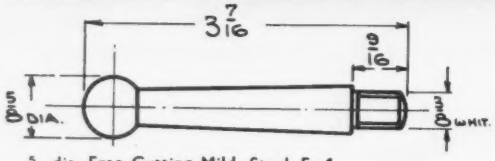

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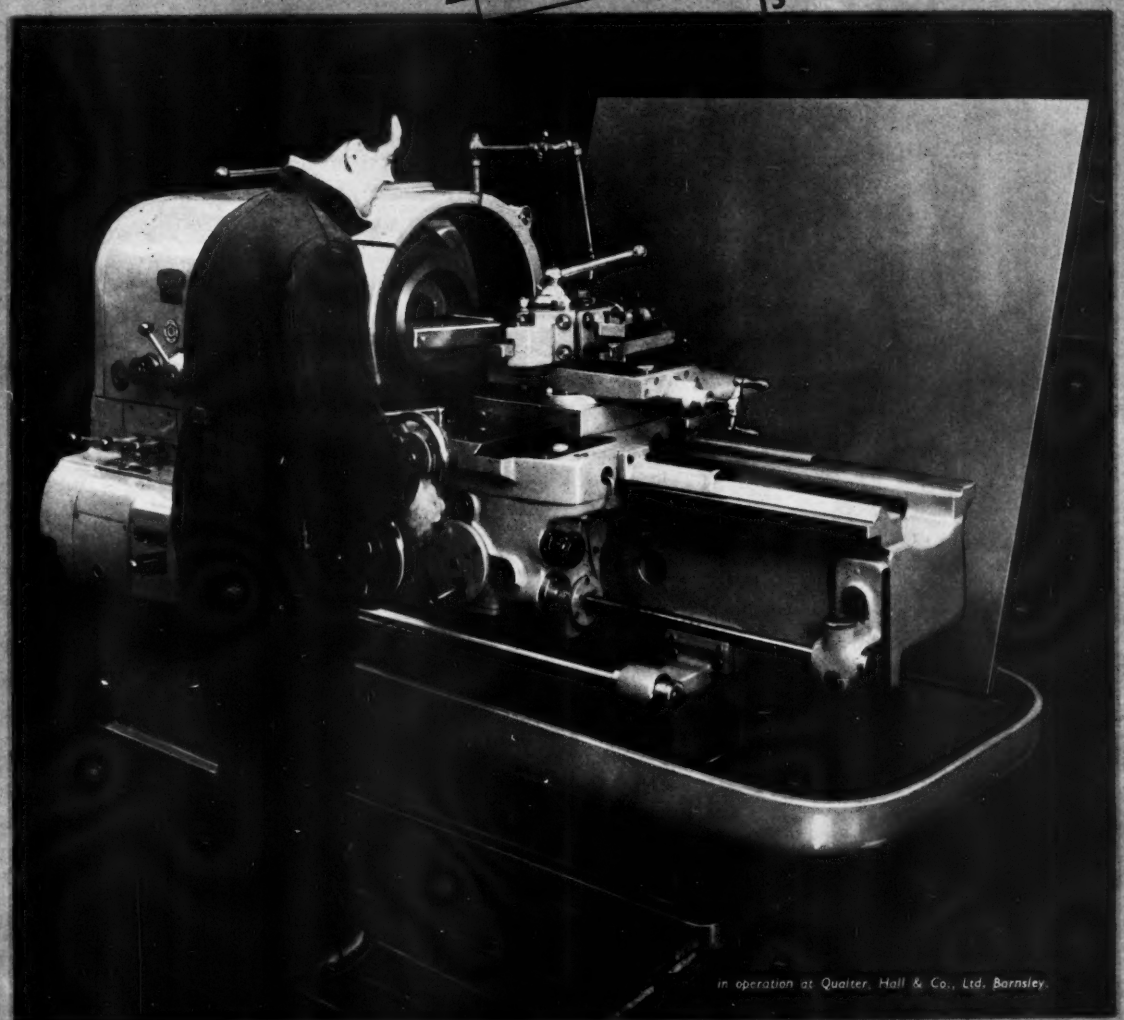

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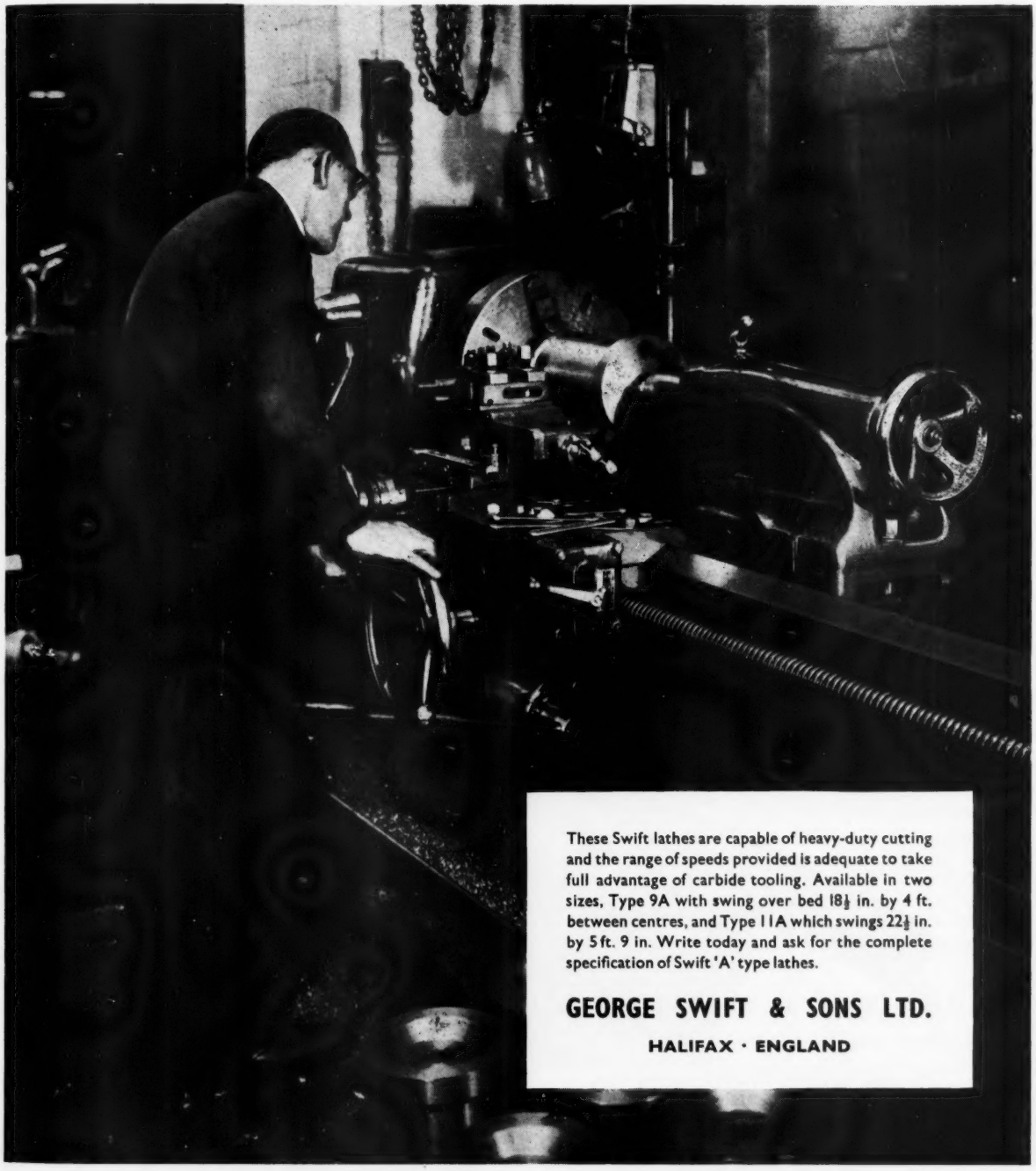

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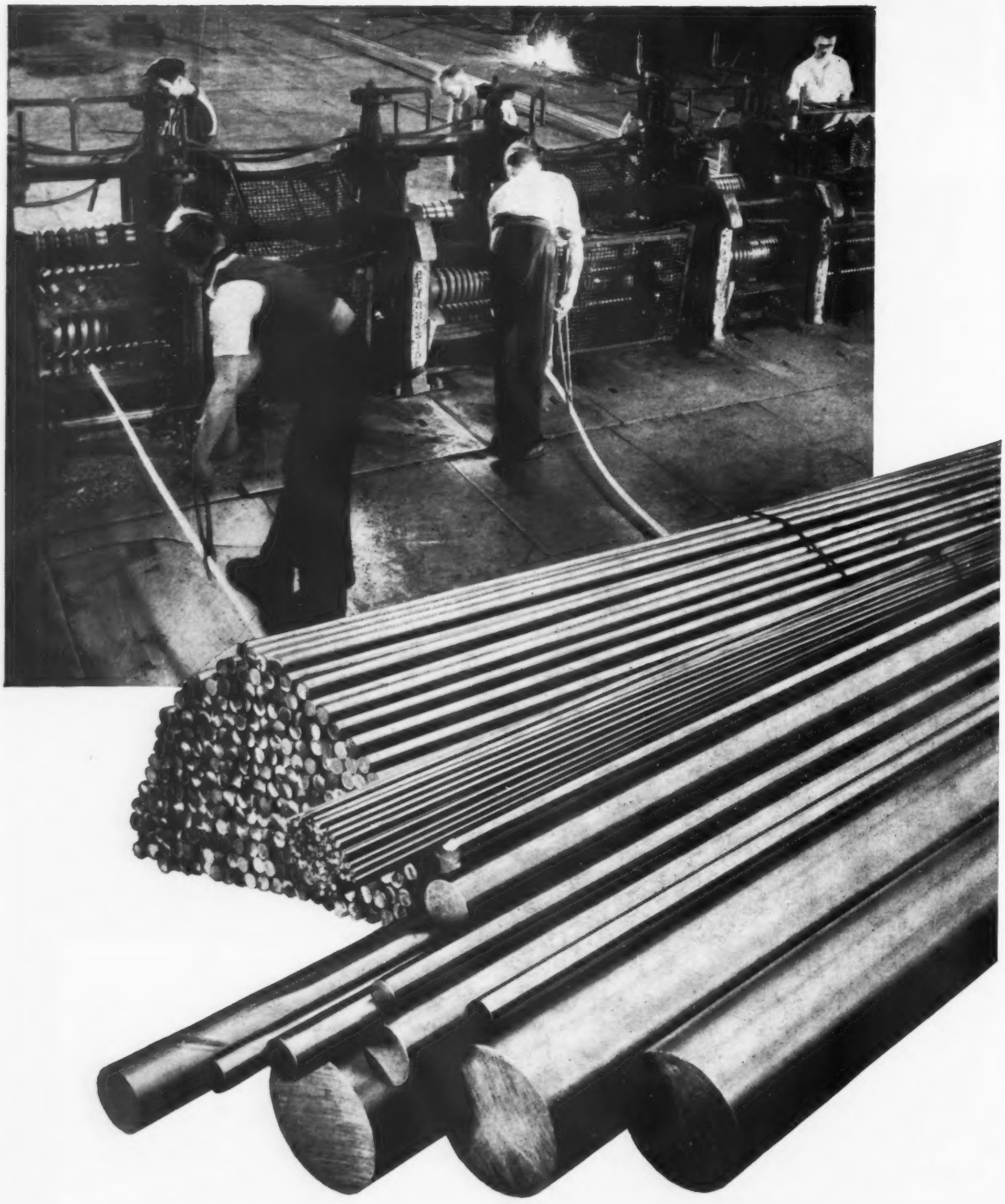

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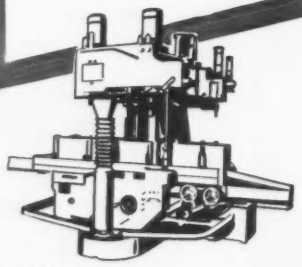

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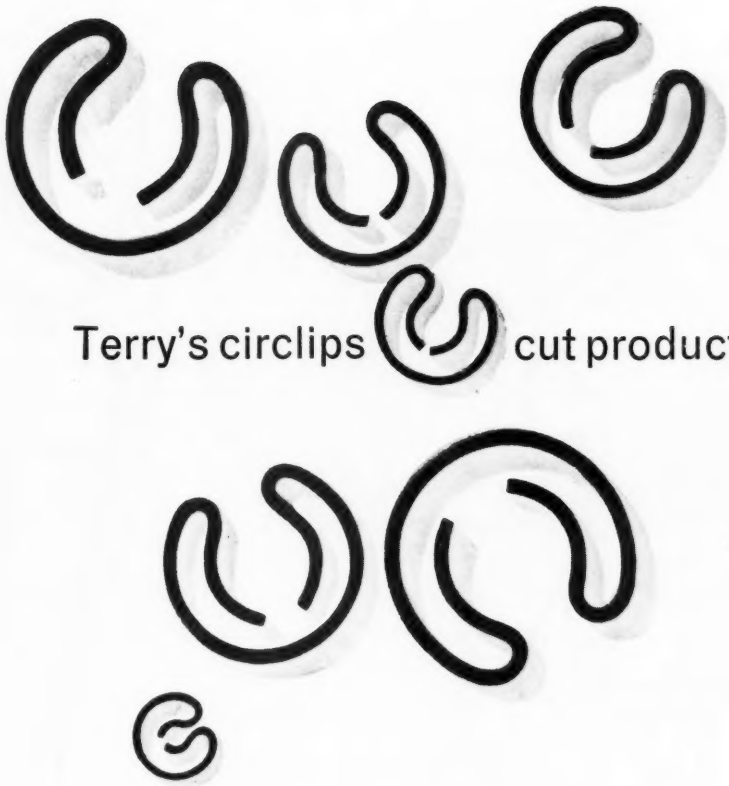

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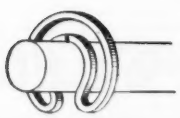

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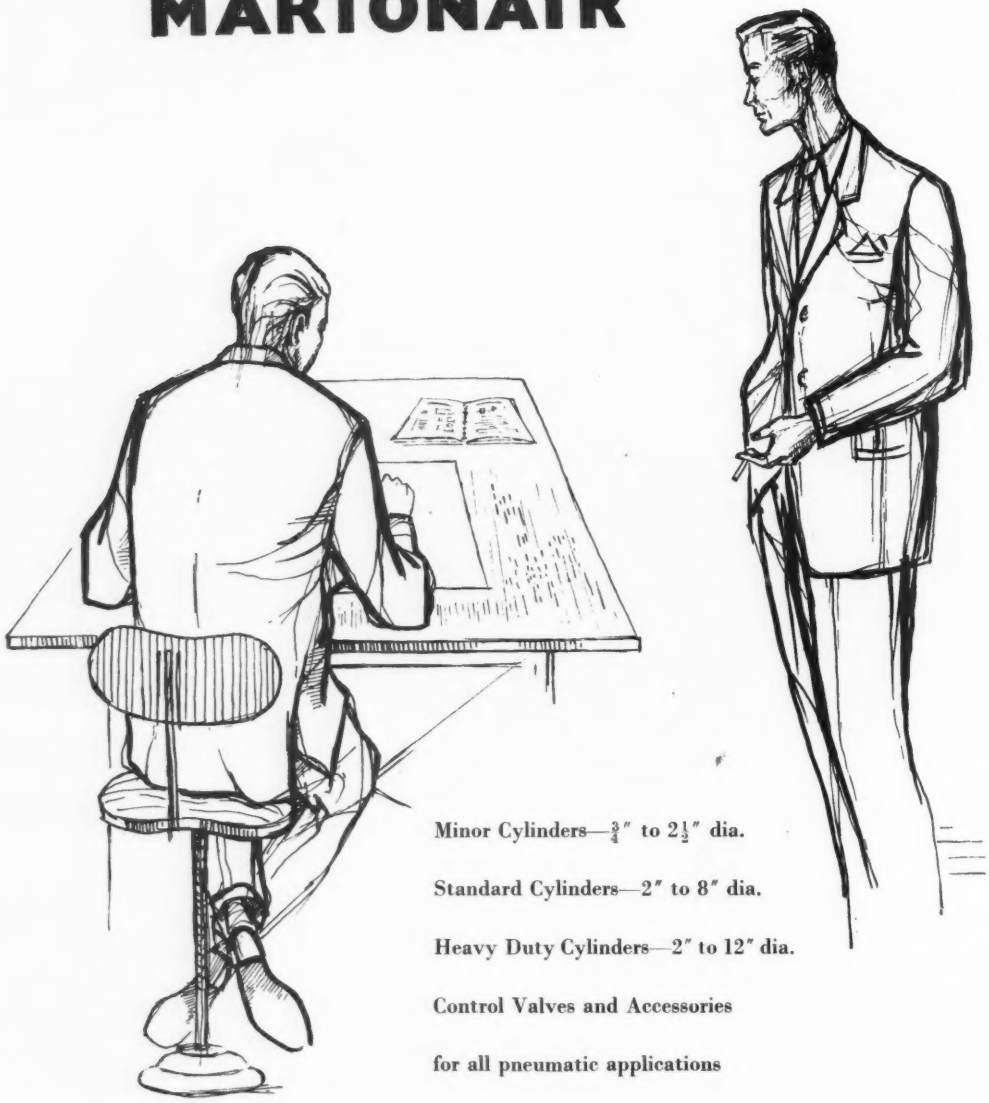

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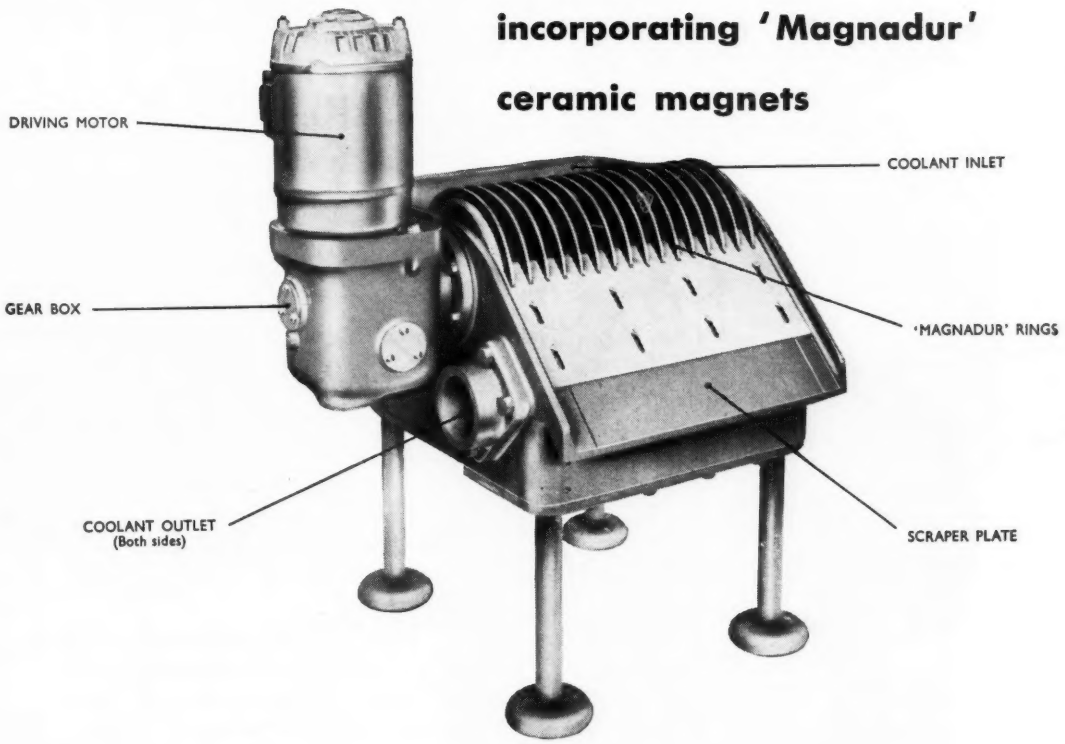

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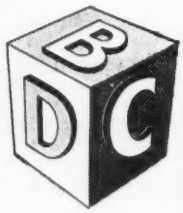

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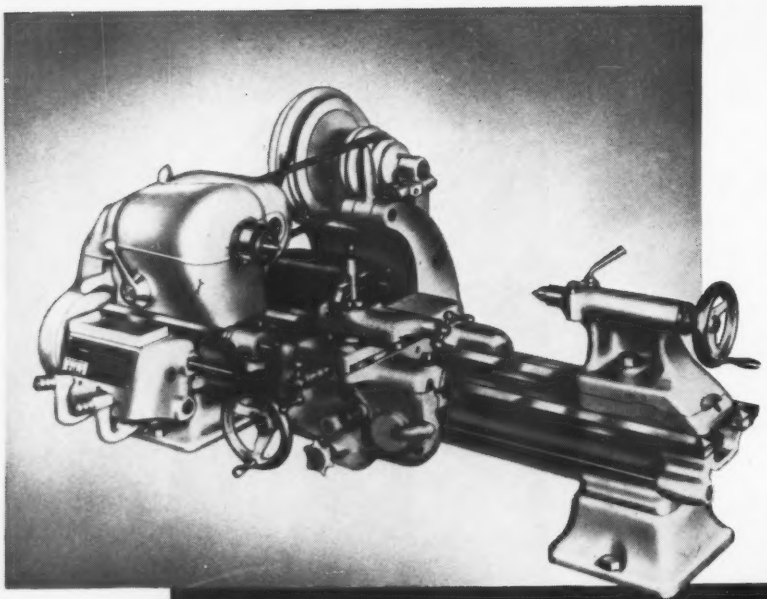

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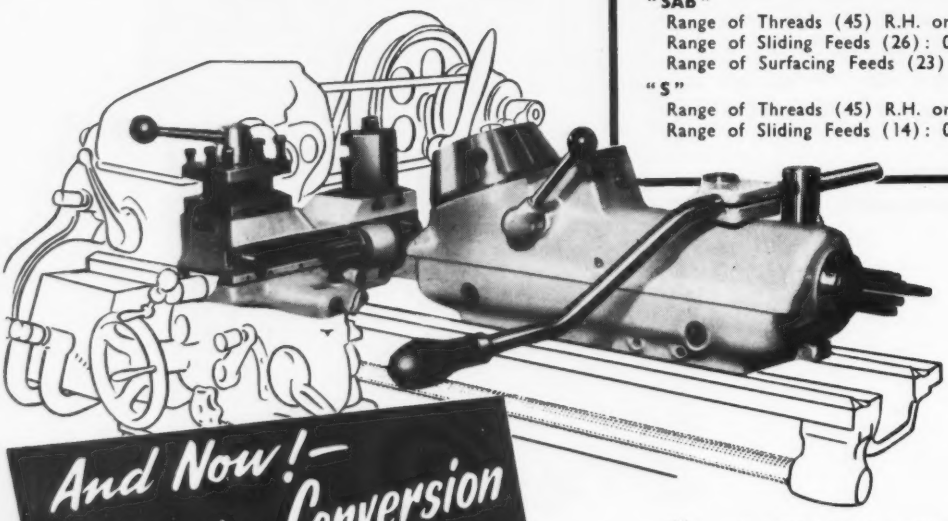

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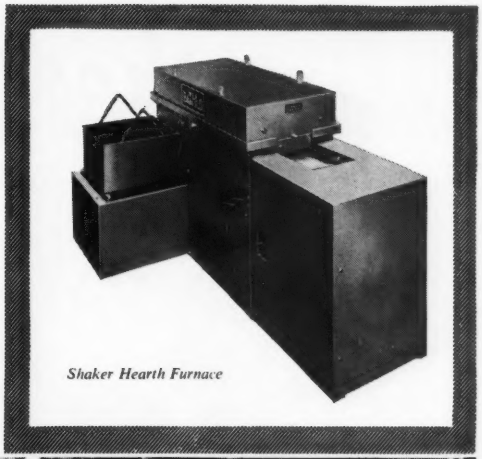
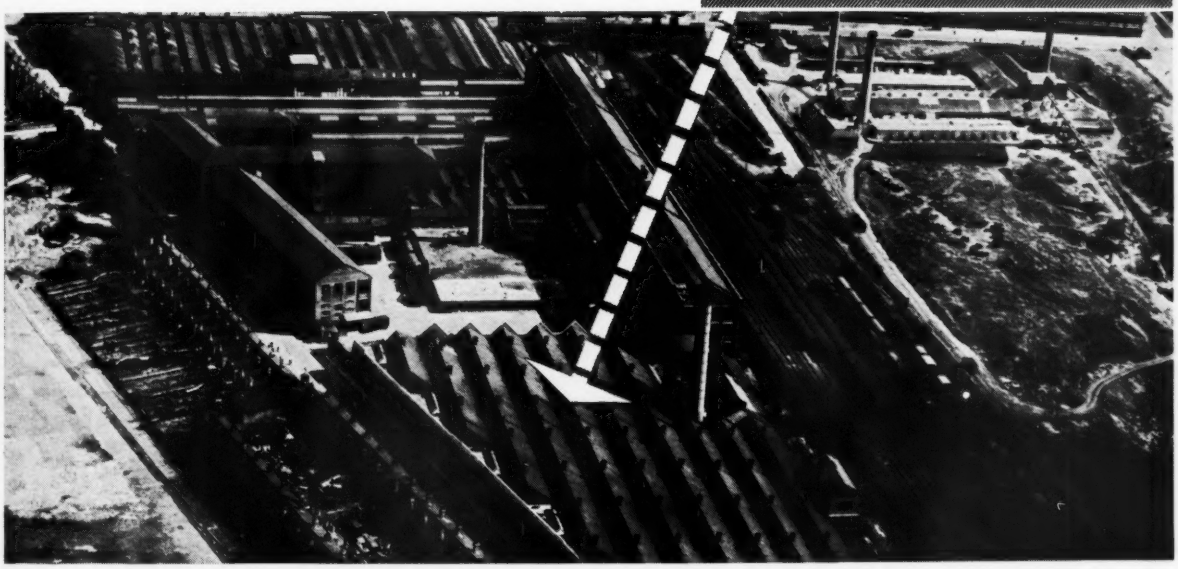


Shaker Hearth Furnace



A Wild-Barfield furnace will bring immediate advantages. It speeds up production and helps to cut costs by eliminating delays and wasteful handling. Built to the highest standards of workmanship, these furnaces offer consistent results and minimum maintenance. The Wild-Barfield Research Department is available at all times to advise you on your heat-treatment problems.

Continuous and batch type furnaces for :

NORMALISING
HARDENING
TEMPERING
GAS CARBURISING
CARBONITRIDING
BRIGHT ANNEALING
and other applications

ELECTRIC WILD BARFIELD FURNACES

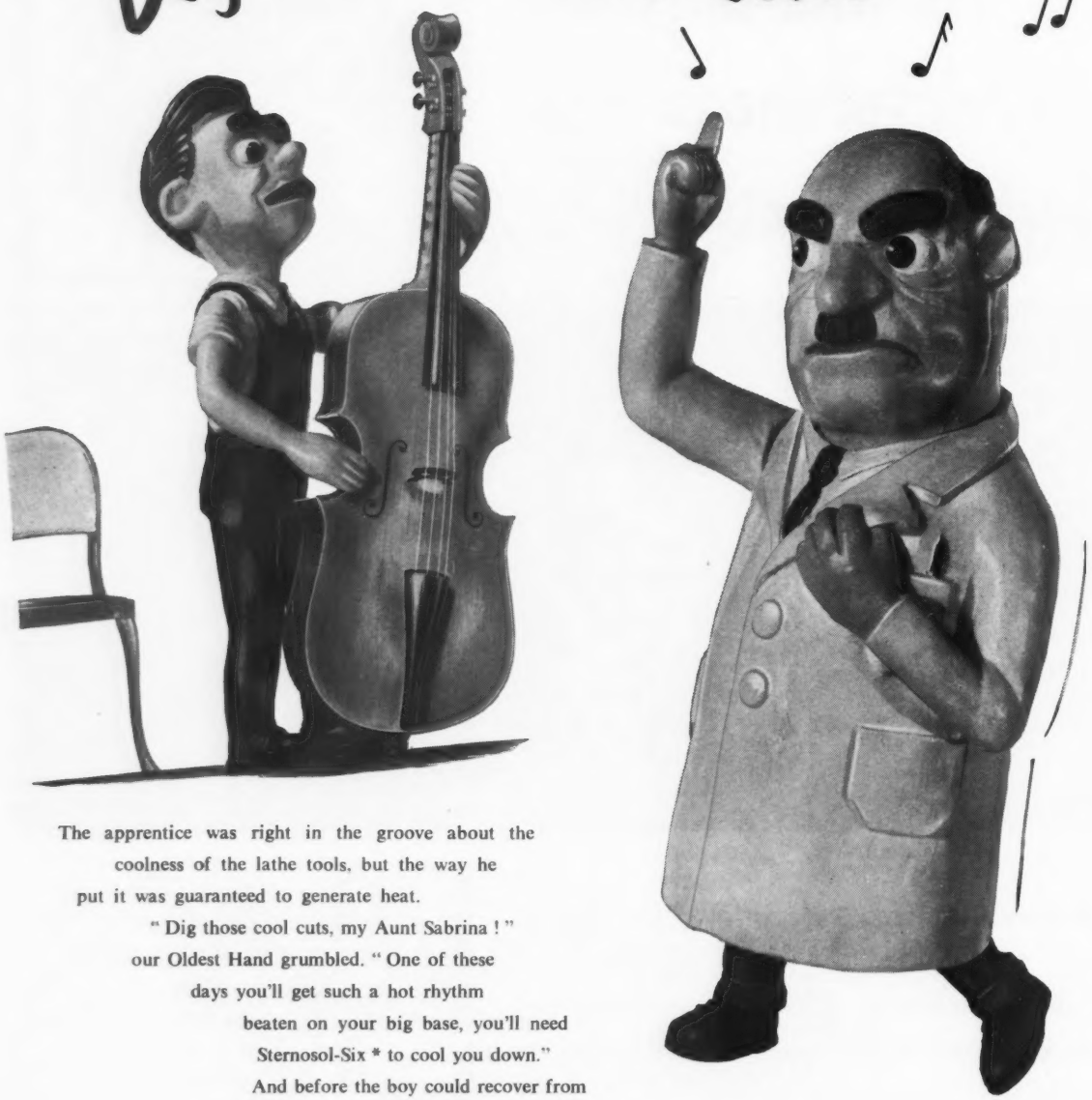
FOR ALL HEAT-TREATMENT PURPOSES

WILD-BARFIELD ELECTRIC FURNACES LIMITED

ELECFURN WORKS, OTTERSPOOL WAY, WATFORD BY-PASS, WATFORD, HERTS. Telephone: Watford 6091 (8 lines)

WB 61

"Dig those cool cuts"



The apprentice was right in the groove about the coolness of the lathe tools, but the way he put it was guaranteed to generate heat.

"Dig those cool cuts, my Aunt Sabrina!" our Oldest Hand grumbled. "One of these days you'll get such a hot rhythm beaten on your big base, you'll need Sternosol-Six * to cool you down."

And before the boy could recover from this, our O.H. made the unkindest cut of all: "Yes, my lad, you'll be a real gone man, unless you use the best cutting oils."

Sternol *cutting oils*

* *Our full range of straight and soluble cutting oils is described in Schedule* SS638.

STERNOL LIMITED · ROYAL LONDON HOUSE · FINSBURY SQUARE · LONDON E.C.2 · MONarch 3871-5

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ANNOUNCE

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CIBA (A.R.L.) LTD

Makers of synthetic resins for industry

REDUX	RESOLITE
AERODUX	ARALDITE
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(registered trade names)

CIBA (A.R.L.) LTD

Duxford, Cambridge

AP 431

NOW STANDARDISING

ON W M LATHES

Westminster Airways Servicing Ltd

GOSPORT, HANTS.

Since 1951, when they installed their first '70' Junior Lathe, Westminster Airways Servicing Ltd., have steadily added to their W & M line. Today they have five '70' Junior Lathes and two '85' Senior Lathes, all employed "with complete satisfaction" on intricate high precision Aircraft Prototype and Tool Work.

In work of this kind, which demands such high standards of accuracy and reliability, "complete satisfaction" is always the aim of W & M.

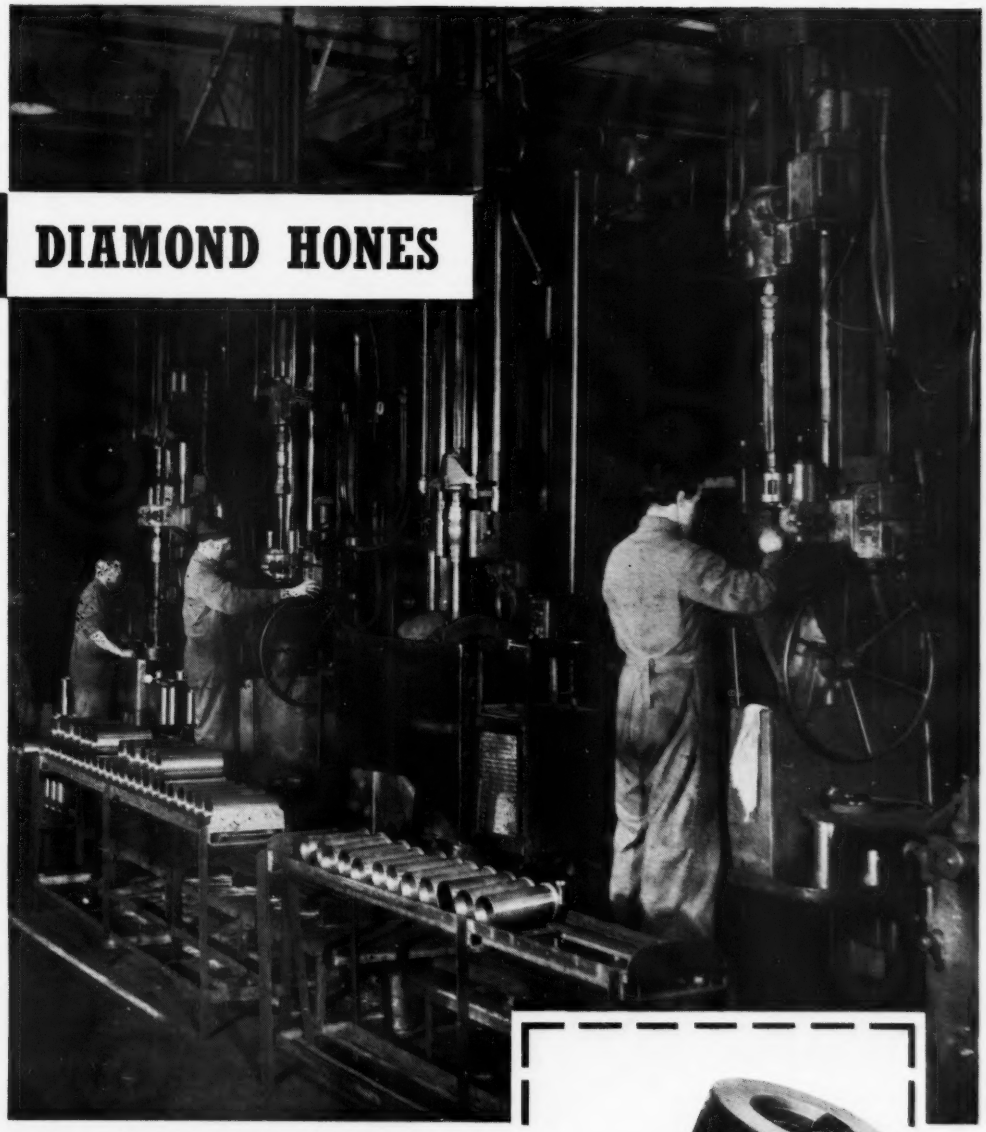
WOODHOUSE & MITCHELL

WAKEFIELD ROAD · BRIGHOUSE · YORKS

PHONE: BRIGHOUSE 627 (3 LINES) — GRAMS: 'WOODHOUSE BRIGHOUSE'

WM21

NEVEN DIAMOND HONES



Photograph by kind permission of Leyland Motors Ltd.

Neven hones are used by the leading engineering firms. The illustration shows our hones in use at Leyland Motors Ltd.

IDP

IMPREGNATED DIAMOND PRODUCTS LIMITED OF GLOUCESTER

TELEPHONE 21164 (3 LINES)
TELEGRAMS IMPREG GLOUCESTER

Neven Diamond Tools Cut, Drill and Grind the Hardest Materials

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More wear resisting than Tungsten Carbide

C.T.B SHOT BLAST NOZZLES

Glostics Ltd

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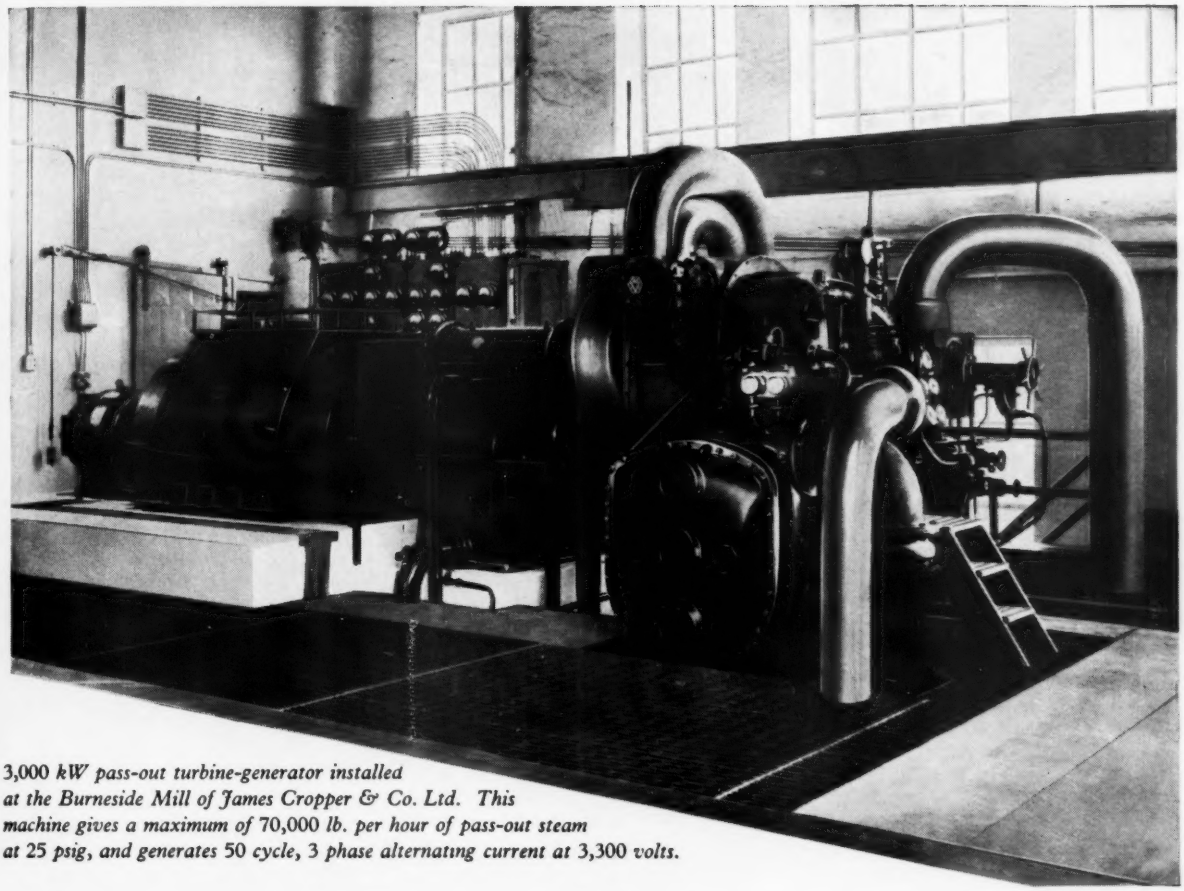

3,000 kW pass-out turbine-generator installed at the Burneside Mill of James Cropper & Co. Ltd. This machine gives a maximum of 70,000 lb. per hour of pass-out steam at 25 psig, and generates 50 cycle, 3 phase alternating current at 3,300 volts.

Steam is costly

-make it work

In many industries where steam is used for processes or heating it is economical to install Metropolitan-Vickers pass-out turbine-generators and so generate electrical power and cut fuel costs.

Metropolitan-Vickers has had considerable experience in the design of self-contained pass-out and condensing steam turbines, and will be pleased to advise on their application in your particular industry.

METROPOLITAN-VICKERS
ELECTRICAL CO LTD TRAFFORD PARK MANCHESTER 17

An A.E.I. Company

Geared Pass-out Turbines for Industry

B/B704

short-handed?

Only *one* pair of hands is required to operate the Azoflex model 42/63 to produce prints in large quantity—dried, flat and ready for immediate trimming and collating. No darkroom, no elaborate ventilating system and ducting are necessary as there are no unpleasant fumes, and therefore AZOFLEX machines are completely mobile to facilitate reorganisation or expansion. Exposing, developing and print delivery are all synchronised for an even flow of finished work, and output in excess of 100 20″×30″ prints per hour can easily be achieved. AZOFLEX is the *only* daylight reflex copying process and it is the *only* photoprinting process to apply a measured dose of developer, thus ensuring optimum quality.

The majority of AZOFLEX photoprinting machines can, subject to certain conditions, be hired as an alternative to outright purchase, where this is preferred.

AZOFLEX MODEL 42/63. Combined synchronised printer and developer. Capacity: cut sheets and rolls up to 42 in. wide. Printing speed: from 6 in. to 15½ ft. per minute. Dimensions: Height 52 in. Width 67½ in. Depth 52 in. with delivery tray extended. Weight: approximately 850 lbs.

ILFORD *Azoflex*

Enquiries to: Ilford Limited,
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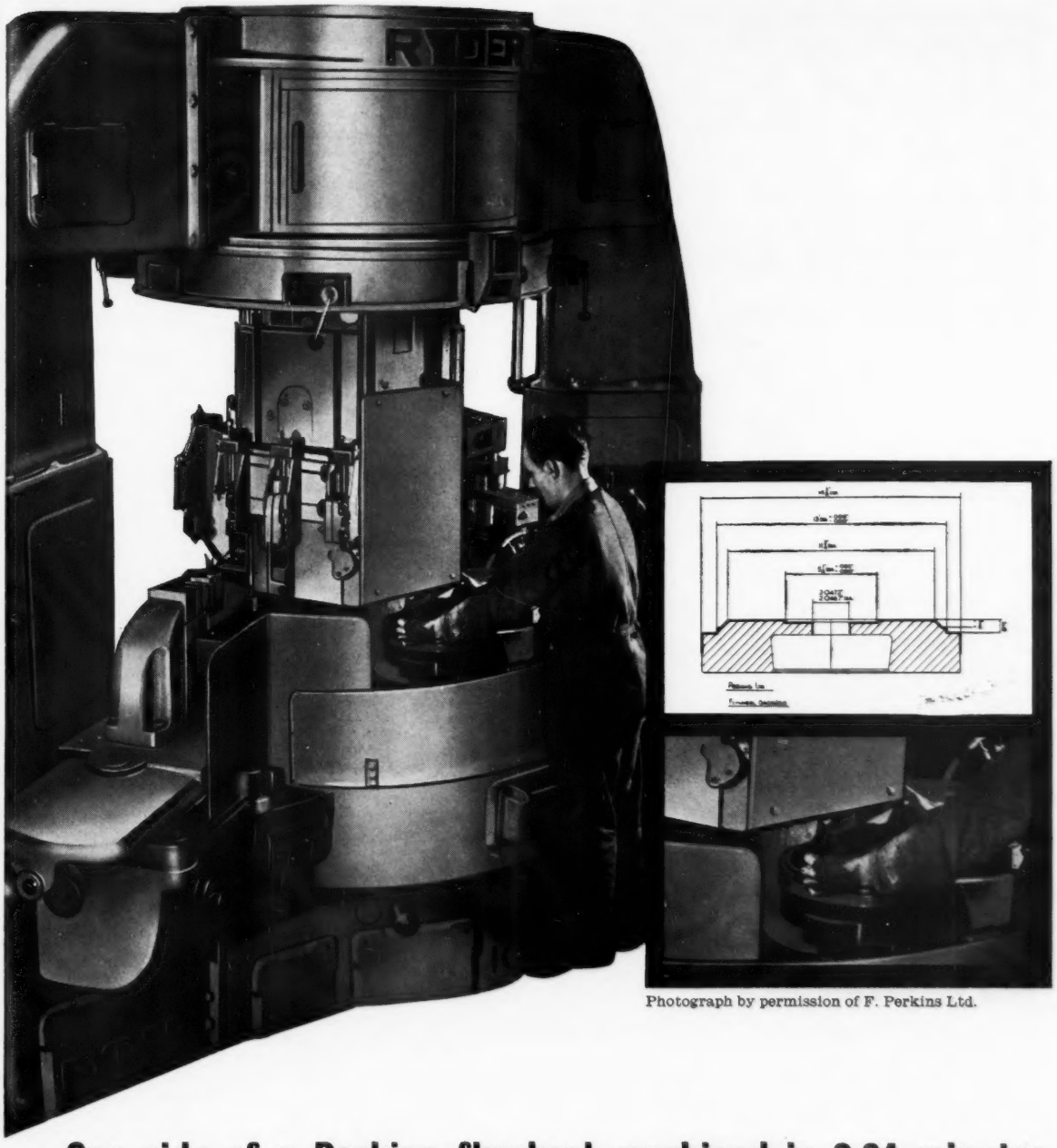
Ilford, Essex
Telephone : Ilford 3000

MACHINES AND MATERIALS FOR DRAWING OFFICE PHOTOPRINTING



Photograph by permission of F. Perkins Ltd.

One side of a Perkins flywheel machined in 2.64 minutes

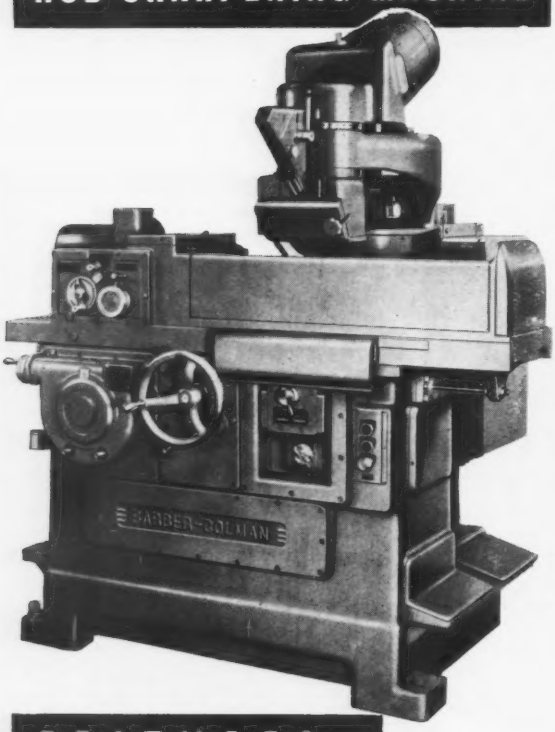
This VERTICALAUTO NO. 10 (six-spindle model) is in the flywheel section of F. Perkins Ltd., Peterborough. It maintains a bore tolerance of .0007″, and crankshaft register and starter ring diameters are held within .002″ and .0015″ respectively. There are nine tooling positions and the six 16″ hydraulically operated chucks are driven by a 60 h.p. main motor.
Eight-and-twelve spindle machines are also available.

Ryder VERTICALAUTO

Thomas Ryder & Son Ltd., Machine Tool Makers, Turner Bridge Works, Bolton, England
Makers also of single-spindle Rydermatics and piston ring lathes

THE NEW

BARBER & COLMAN 6-5 Hydraulic HOB SHARPENING MACHINE



FEATURES

- ★ PRECISION SET-UP ADJUSTMENTS
- ★ WET OR DRY GRINDING
- ★ ACCURATE INDEXING
- ★ PRECISION BUILT-IN WHEEL DRESSER
- ★ ADJUSTABLE HYDRAULIC TABLE SPEED AND STROKE
- ★ AUTOMATIC FEED AND INDEX COUNTING
- ★ UNIT CONSTRUCTION

The new Barber-Colman No. 6-5 Hydraulic Sharpening Machine is a precision machine which controls index spacing, rake angle, lead of gash, and surface finish of the cutting tool to a degree which has never before been reached by any commercial sharpening equipment. Illustrated literature available on request.

BARBER & COLMAN LIMITED
BROOKLANDS SALE CHESHIRE
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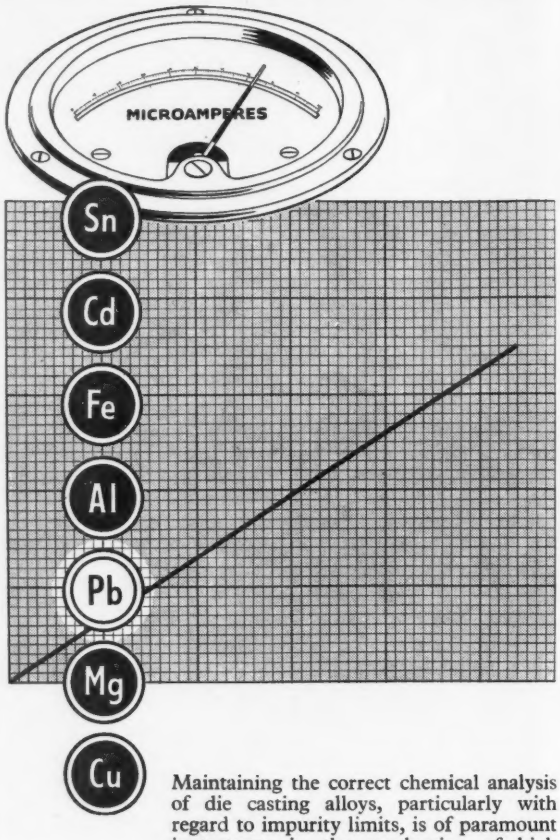
QUALITY CONTROL of pressure die castings



Maintaining the correct chemical analysis of die casting alloys, particularly with regard to impurity limits, is of paramount importance in the production of high quality die castings. Our Laboratory is equipped with one of the few *direct reading spectrographs* in use in this country. As a result the requirements of the B.S.I. Certification Scheme for zinc alloy die castings are far exceeded. Every melt is analysed and the holding furnace of every machine is checked for impurities at least once per shift, enabling any variance from specification to be quickly identified. With the utmost confidence, we can therefore claim to supply castings only of the highest quality.

BS 1004

Quotations, without obligation, from drawings, specifications or samples.

PRESSURE DIE CASTINGS
IN ZINC, ALUMINIUM AND SOFT ALLOYS

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DIE CASTING DIVISION
Tottenham, London, N.17

Conveyor belts, flat or troughed, enjoy a longer life even on the heaviest duty and in the roughest service conditions when they are used with smooth running and robustly constructed NEWCON idlers and drums.

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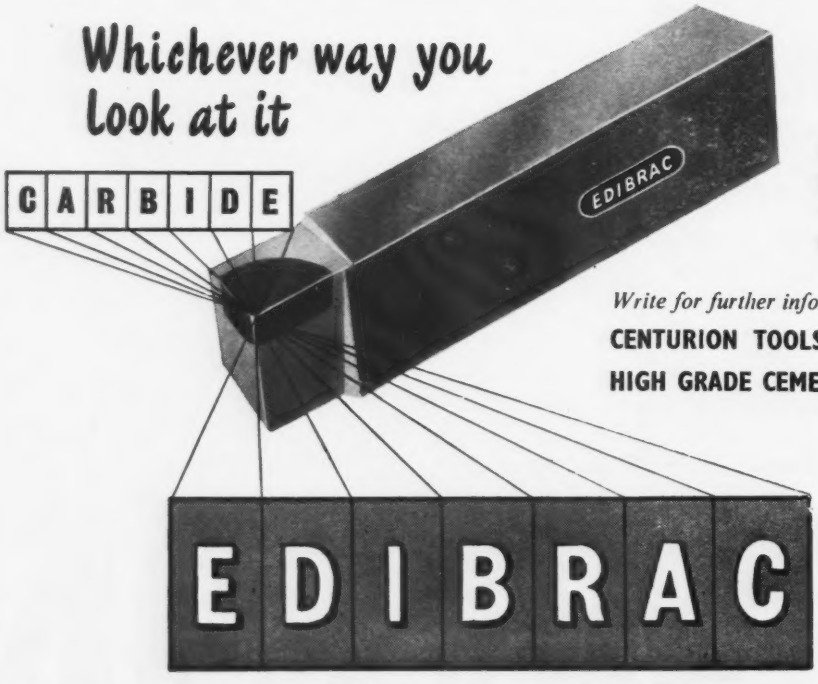
F/4/1

Whichever way you look at it



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A completely self-contained and compact machine, the 'K.S.E.' is designed for high speed, accurate grinding of bores from 3/16" to 1 5/8".
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A 60,000 R.P.M. electrically driven high speed grinding spindle producing 5 MM. bores at the Bracknell factory of
E.M.O. INSTRUMENTATION LTD.

TOOLROOM PRECISION *plus* PRODUCTION OUTPUT!

TWO MODELS FROM OUR RANGE

CARDIFF *'SENIOR'*

8½" S.S. and S.C. LATHE

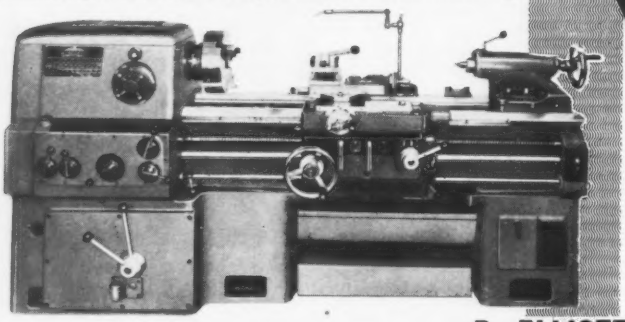
Gap Bed 30", 48" or 80", alternatively Chip Flow Bed 48" or 80"

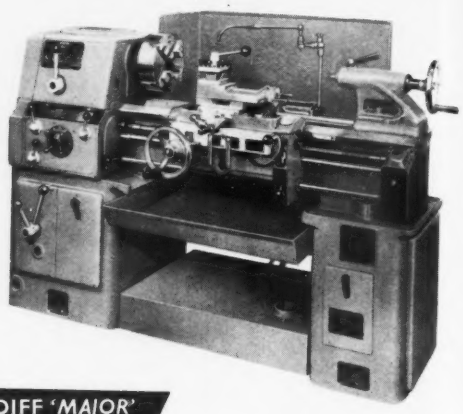
18 Spindle speeds 20 to 970 r.p.m., higher and lower ranges optional

Patented totally enclosed feed box providing wide range of threads and feeds

Hardened and ground gears in gearbox and headstock—all meshing faces tooth rounded for easy engagement

Patented snap action feed controls on apron–feeds can be varied whilst cutting





CARDIFF *'MAJOR'*

7½" S.S. and S.C. LATHE

Gap Bed 40" or 60", alternatively Chip Flow Bed 30", 40" or 60"

18 Spindle speeds, 27 to 757 r.p.m. or 35 to 1000 r.p m.

Patented totally enclosed feed box providing wide range of threads and feeds

Hardened and ground gears in gearbox and headstock—all meshing faces tooth rounded for easy engagement

Patented snap action feed controls on apron

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(MEMBER OF THE B. ELLIOTT GROUP)

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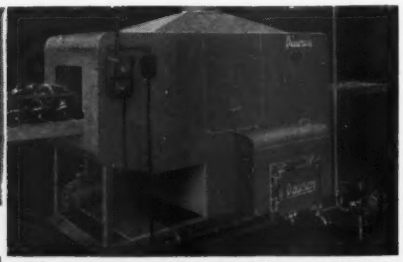
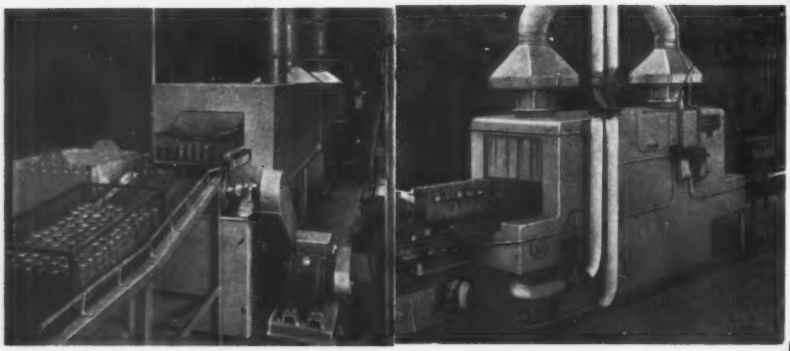
The most practical plant for Cleaning METAL PARTS

PRIOR TO ASSEMBLY, and BEFORE and AFTER REPAIRS



A 'Junior' type machine supplied to a Midlands Motor Car Works.



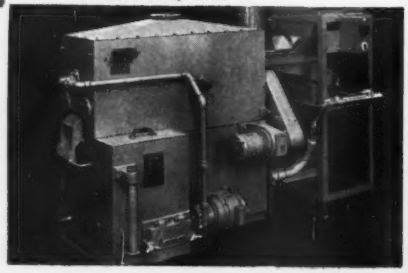
Supplied for the washing and drying of Tractor parts. Crank Shafts, Sumps, Pressings, etc.

A model 'A' machine washing parts of motor car engines prior to assembly.

Dawson

DE-GREASING AND CLEANING MACHINES

A Rotary Drum machine for removing swarf and grease from small components.



Dawson Metal Parts cleaning machines are supplied for all branches of the engineering industry. Their chief characteristics are robustness of design, small number of working parts and simplicity of operation. Space only permits the illustration of four of the many types of machines built for quick economical washing and drying of Metal Parts.

Sole Distributors

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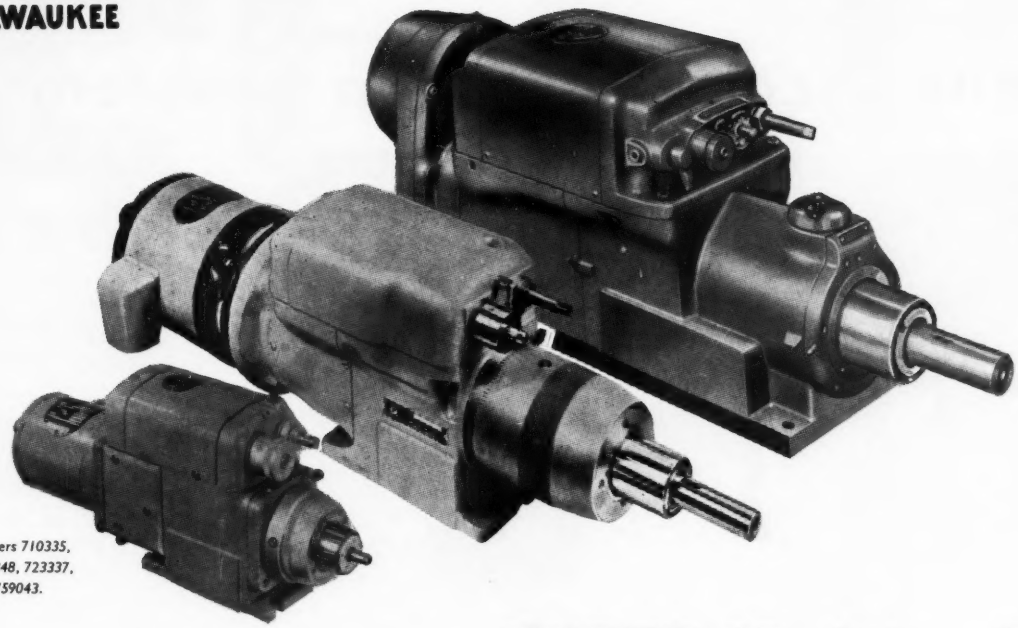
Manufacturers—DAWSON BROS. LTD., Gomersal, LEEDS *Tel.—Cleckheaton 1080 (5 lines)*

London Works—406 Roding Lane South, Woodford Green, Essex. *Tel.—Wanstead 7777 (4 lines)*

DELTA
MILWAUKEE



Patent Numbers 710335, 719846, 721848, 723337, 723871 and 759043.

THREE Models of
DELTA Drill Units
AIR POWERED-HYDRAULIC CONTROL

A PRACTICAL LOW-COST WAY TO SOLVE MACHINING PROBLEMS INVOLVING DRILLING, TAPPING, REAMING, SPOT FACING, HOLLOW MILLING, CHAMFERING, CENTREING, COUNTER-SINKING AND THE LIKE — USE THE DELTA DRILL UNIT TO DEVISE SPECIAL TOOL SET-UPS THAT MULTIPLY PRODUCTION, BREAK BOTTLENECKS.

Rarely has a new machine achieved success so completely and so quickly as this new Delta air-powered hydraulically controlled Drill Unit.

Thousands of manufacturers, on the alert for ways to get better production faster and at least cost, have won astonishing benefits by means of this adaptable unit — by designing special machines for multiple and series operations.

YOU'LL APPRECIATE "WHY" WHEN YOU CHECK THESE REASONS:

1. Quick set-up. No cams.
2. Ability to set most economical cycling.
3. Infinitely variable control.
4. Stroke length controllable to .0005 in. accuracy.
5. Hydraulic controlled power feed . . . independent of motor and spindle speed.
6. Compressed air provides thrust on a sealed, pumpless hydraulic system to move spindle forward. No lost motion . . . no backlash.
7. Sealed unit construction permits operation in any position.
8. Built-in electrical control switches, permitting interlock with further units and/or mechanisms.
9. Direct drive, gear drive or pulley drive available.
10. Ability to use multi-drill or tapping attachments.
11. Operates from standard plant 80 p.s.i. air supply.
12. Rugged design and simple operating principle ensures long, trouble-free service.

Three models are available:

MODEL 19-150 — Capacity up to $\frac{5}{16}$" - $1\frac{1}{2}$" stroke.

MODEL 19-400 — Capacity up to $\frac{5}{8}$" - 4" stroke.

MODEL 19-600 — Capacity up to $1\frac{1}{2}$" - 6" stroke.

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Mild steel fabrication problems

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Typical run of ducting supplied to a large glass manufacturing concern. Ducting fabricated throughout from ¼" mild steel plate, and ranging from 4'-0" to 6'-0" diameter.

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★ *Work performed to Lloyd's class 2 specification*

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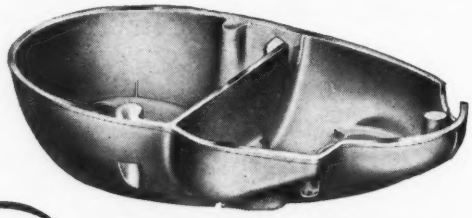
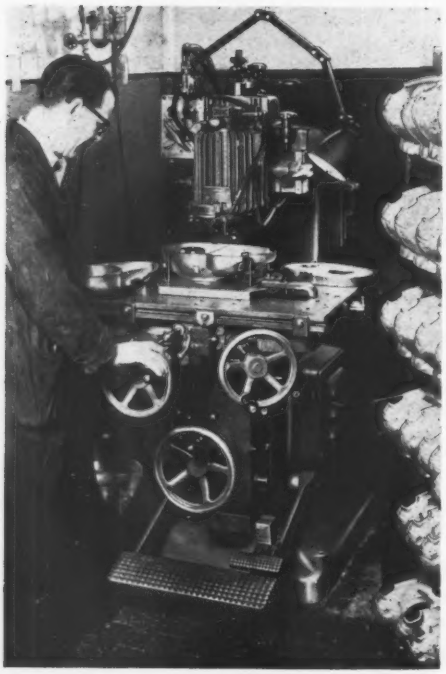
MACHINING TIME CUT BY NEARLY 2/3





on Villiers magneto covers

PREVIOUS METHOD *Face milling on vertical miller*	**13** pieces per hour
PRESENT METHOD *Face milling on Wadkin Router*	**32·4*** pieces per hour

* *When the operator becomes fully proficient in the operation of the Wadkin Router, the rate of production is expected to reach 37 pieces per hour.*

The Wadkin High Speed Router does the face-milling operation on this light alloy magneto cover with a saving of more than 60% of former machining time. This is not an unusual result — it's typical of the Wadkin Router's performance on Non-ferrous Metals. Unlike conventional machines the Wadkin L.S.M., shown on left, has cutting speeds up to 24,000 r.p.m. This guarantees a perfectly machined face requiring no further finishing operation, and only light clamping of the component is necessary.

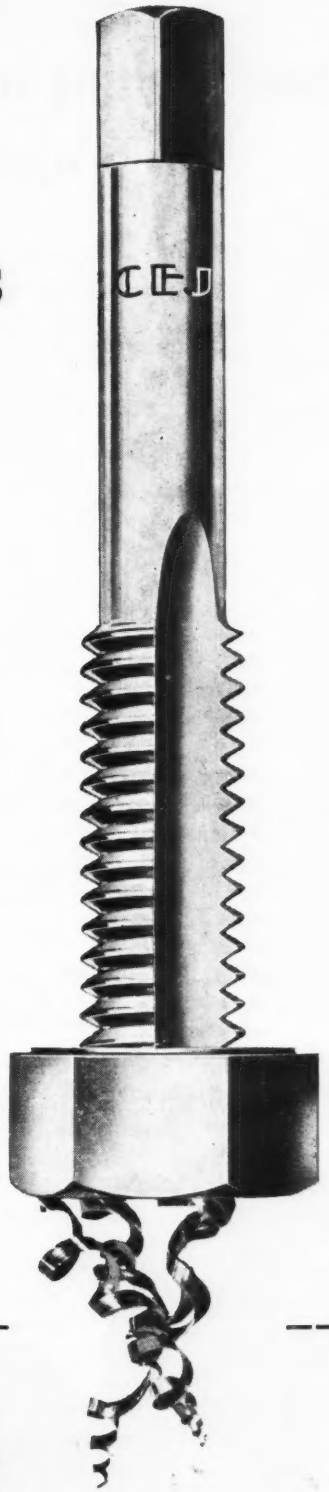
Wadkin

Tel: Leicester 68151 *Tel: MAYfair 7048*

Wadkin Ltd., Green Lane Works, Leicester. **London Office: 62 Brook Street, W.1**

CEJ

THREADING TOOLS



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Ground Thread Taps
Chaser Dies
Screw Plug Gauges
Screw Ring Gauges
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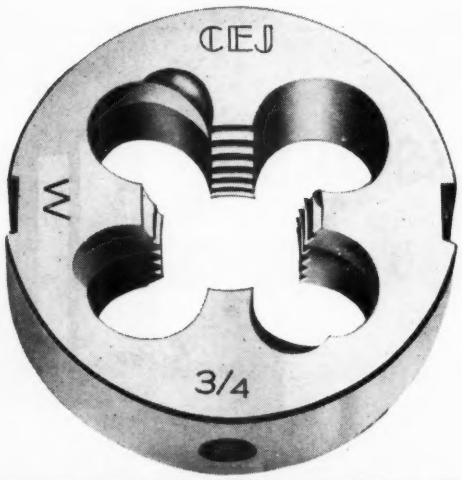
Round Dies
Thread Milling Hobs
Thread Rolling Dies
Plain Plug Gauges
Mikrokators
Micro Snap Gauges
Surface Finish Indicators
Micrometers
Bore Gauges
Deltameters (Automatic Sizers)
Drill Chucks
Gauge Blocks
Dynamometers
Extensometers
Plain and Screw Snap Gauges
Plain Ring Gauges
Gronkvist Drill Chucks
Dial Gauges
Tapping Attachments
Multiple Interference Microscopes
Vernier Height Gauges



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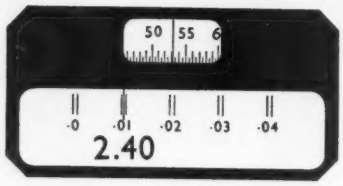
DHB/2367

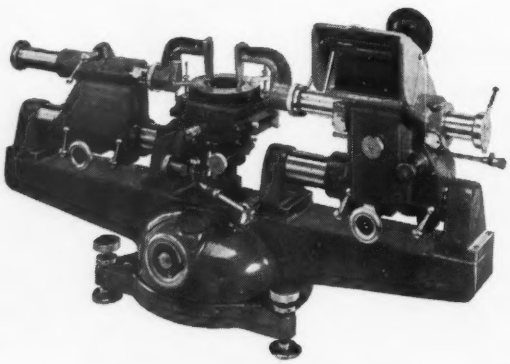
Direct reading to 0.00005 in. on projection screen



FIELD OF VIEW

½ actual size

All measurements with the Microptic Horizontal Measuring Machine are read in large clear figures from a $3\frac{3}{4}$ in. wide screen. Reading is simplified, setting more accurate, eyestrain eliminated. Ideal for use in Testing and Standards Rooms and for routine measuring of all types of internal and external work. Any number of measurements over a four inch range can be made with one standard setting. Capacities: Internal $\frac{7}{16}$ to 10 ins., External 0 to $13\frac{1}{2}$ ins. Metric reading model available. Length 35 ins.; height 22 ins.; width 14 ins.



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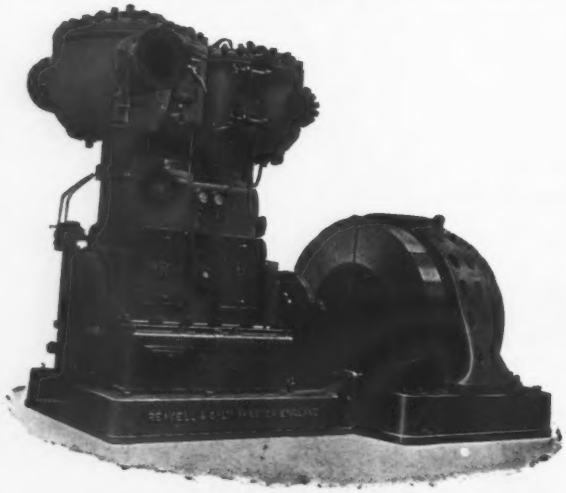

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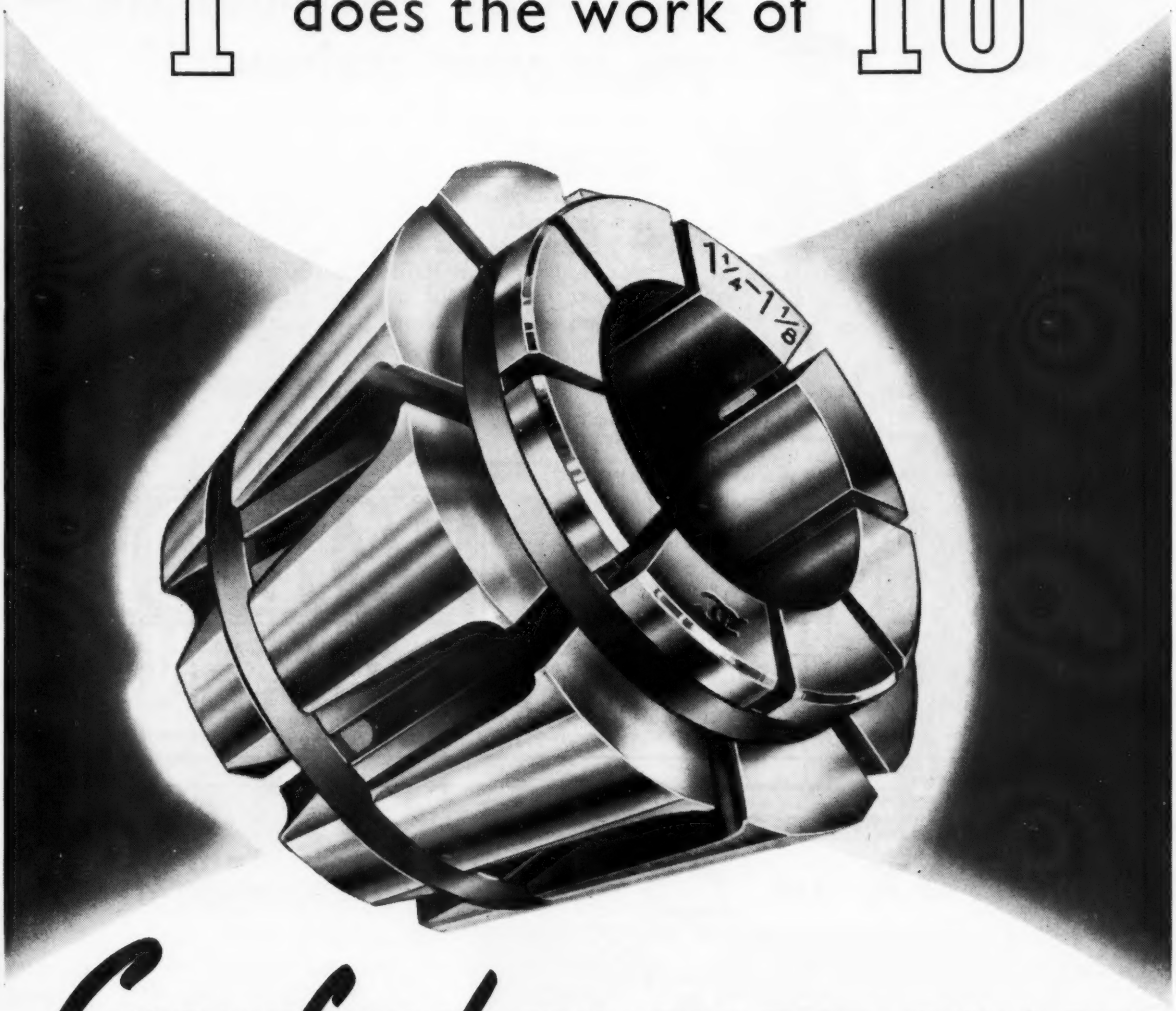

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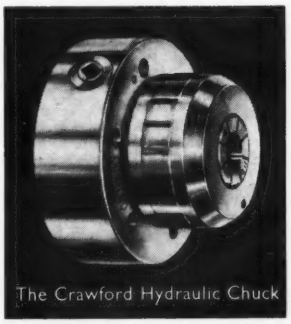
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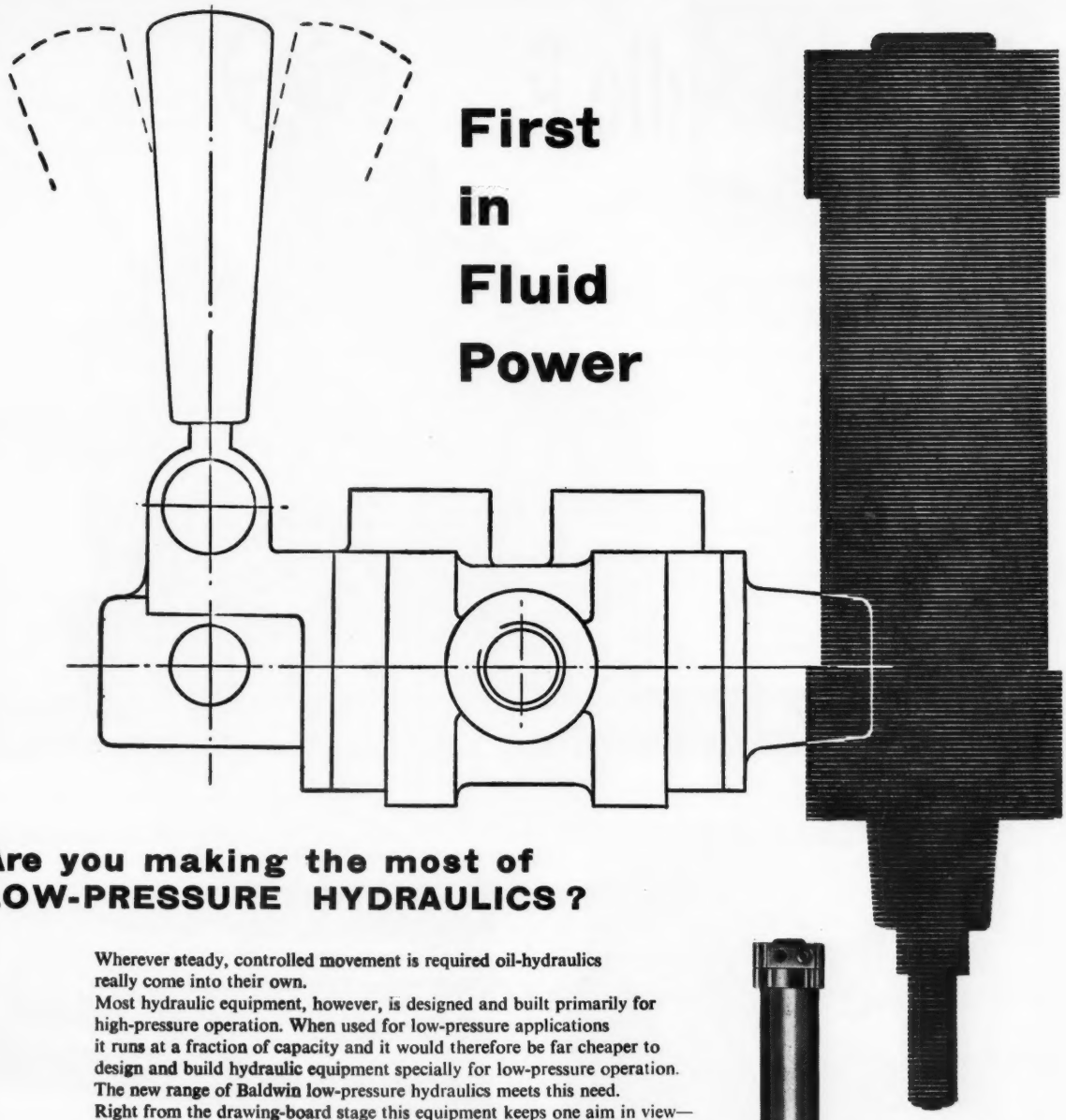

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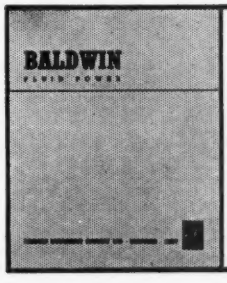

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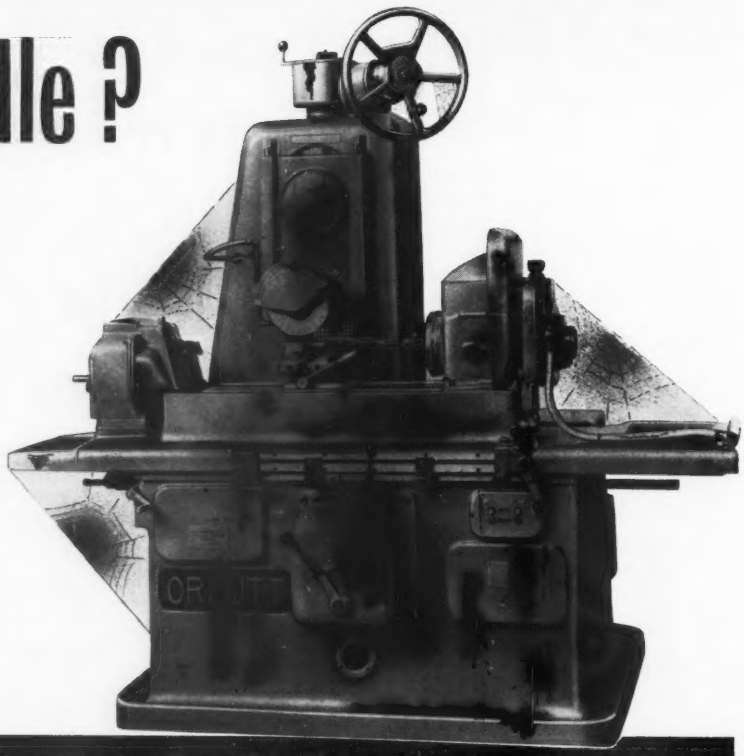

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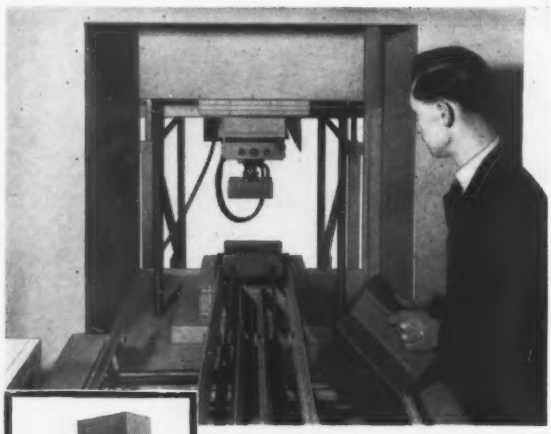

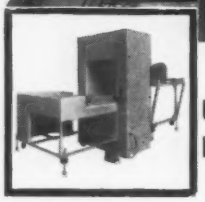

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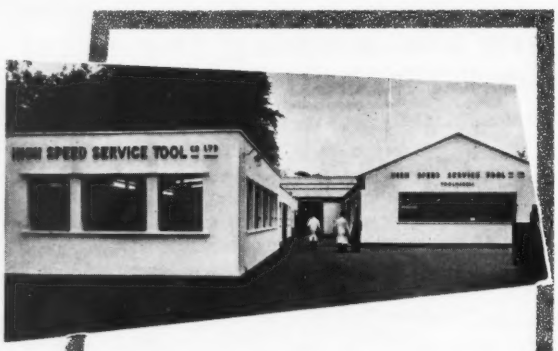

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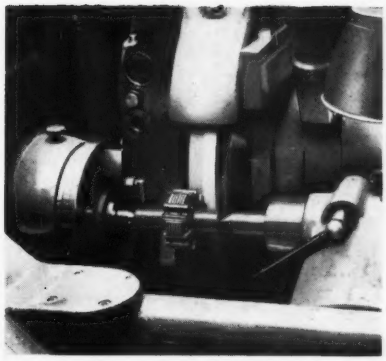

Thread grinding the anvils.

As there are no projections from the side of the caliper frame it is suitable for gauging shouldered work.

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WINGS DAY SEPT. 20th GIVE FOR THOSE WHO GAVE

The Horstmann Model 52 Screw Caliper Gauge puts accuracy in your hands. In addition to the features displayed above, it incorporates many other advantages, all of which contribute to fine accuracy, versatility, long life and ease of handling. The anvils are set so that they do not roll — all shearing action is eliminated — the caliper is suitable for either left- or right-hand threads — and it is ideal for gauging Acme forms and shouldered work. Model 52 is available in a full range of B.A., American, Unified, Whitworth and Metric forms of thread.

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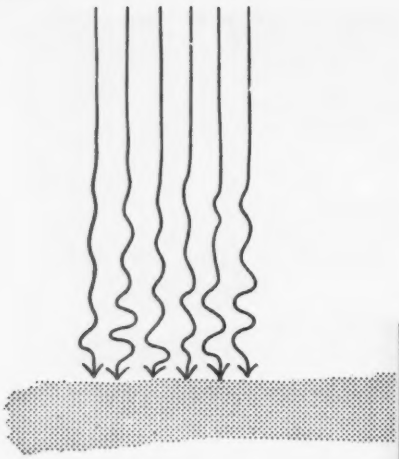

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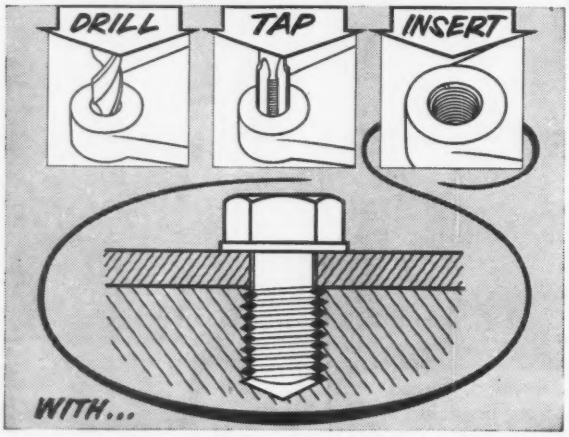
CUTS SCRAP COSTS! SIMPLY



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The spindles are accurately ground to fine limits and the rack teeth are cut into the spindle sleeve.

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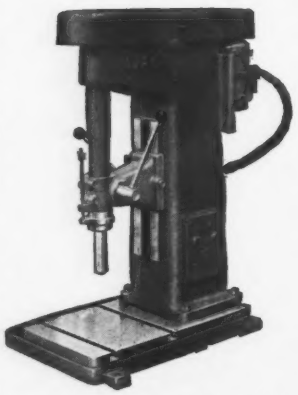

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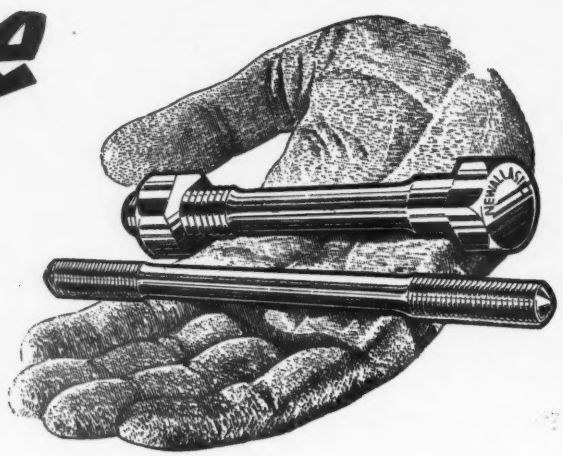

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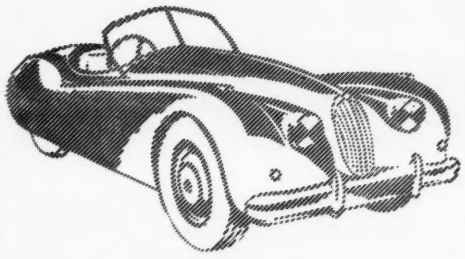

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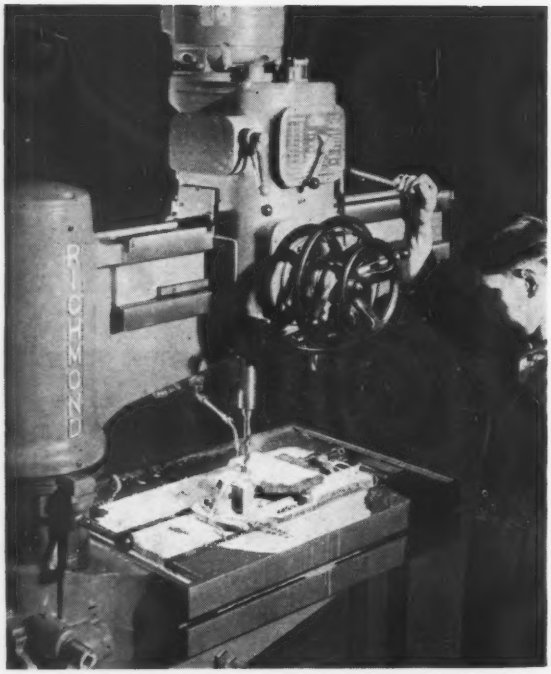

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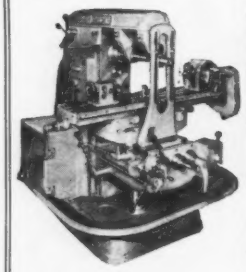

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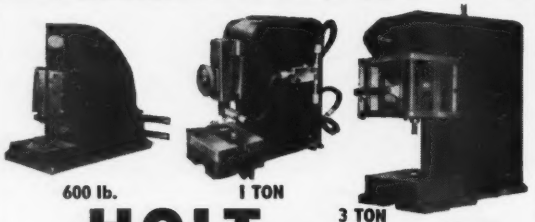

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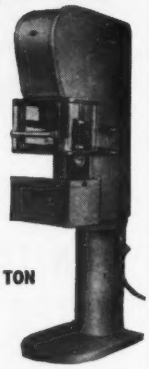

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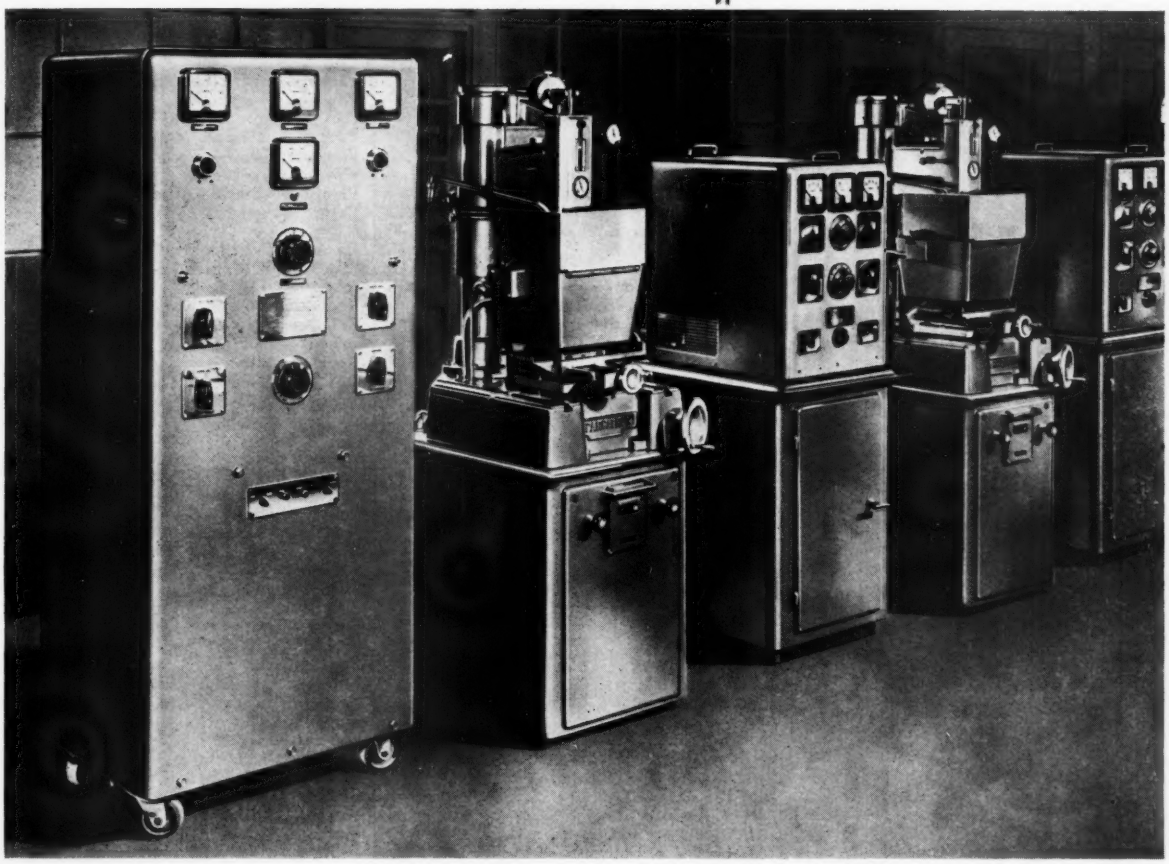

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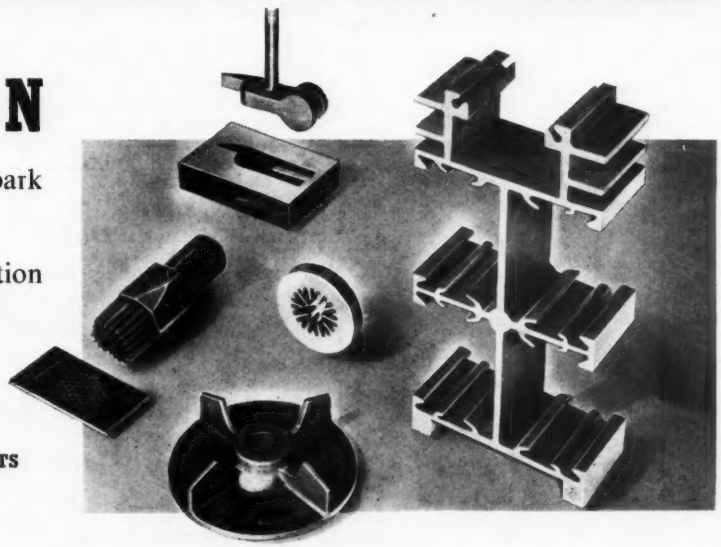

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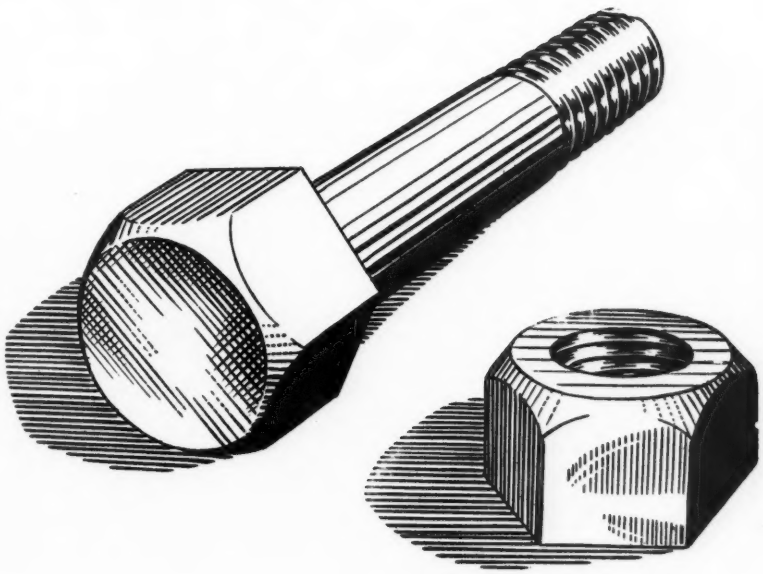

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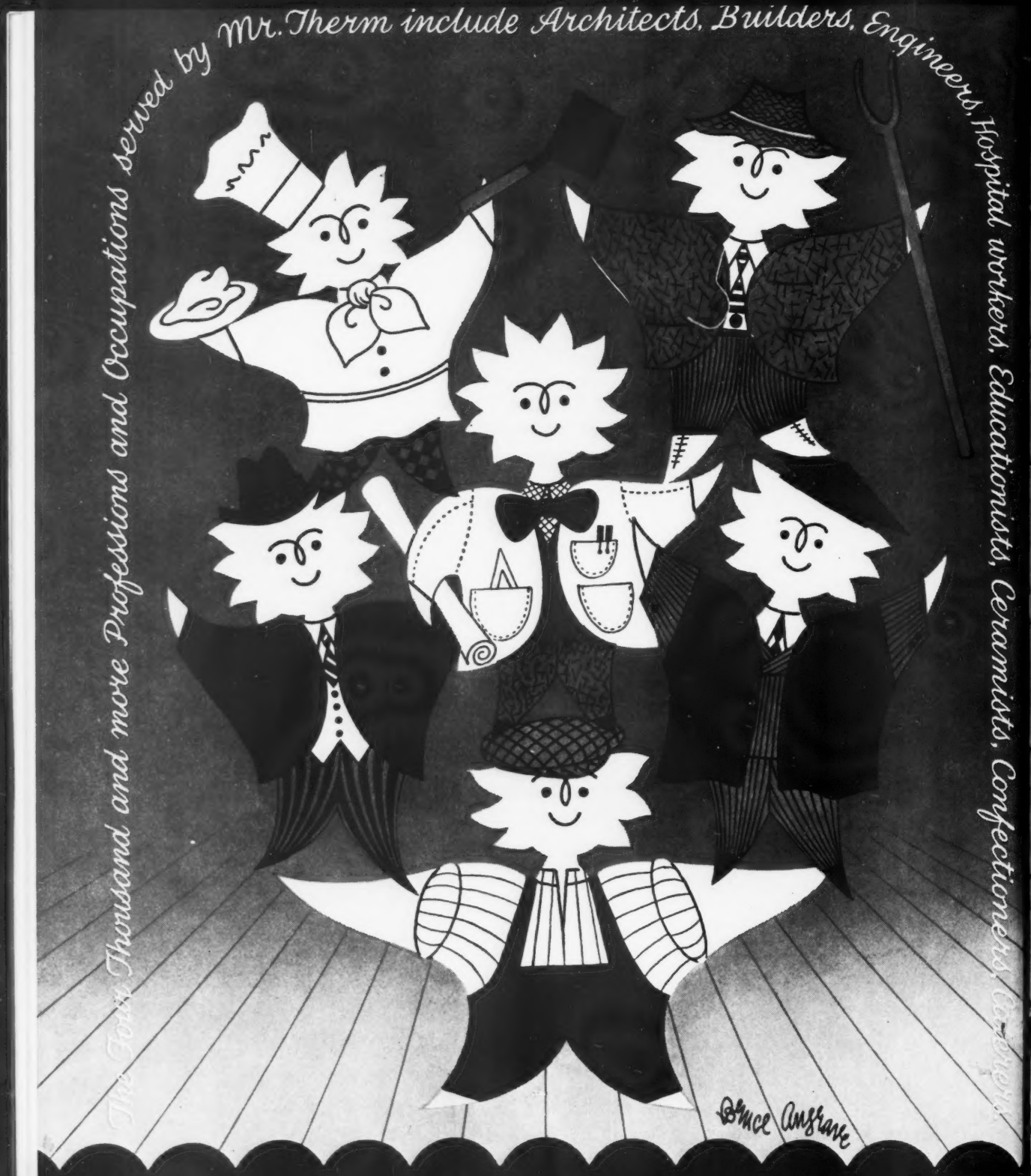
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